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Heavy Civil Earthwork Construction
Part 1. An Introduction

by

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Introduction

Heavy Civil Earthwork involves moving earthen materials for an excavation or embankment construction activity. As an introductory course the material will consider these activities in very broad terms to familiarize the reader with some general earthwork operations. This course is designed to give a brief overview of the construction practices and procedures of this very important subject to Heavy Civil Construction Projects. It will discuss common terms and definitions, review the basic materials and equipment used, basic construction engineering roles and responsibilities, briefly describe some specialized earthwork operations, and lastly a statement

concerning construction safety. All of these topics for the various types of excavation and embankment construction, will be presented as an introduction only, and possible future-more specific courses on the subject matter may be added to supplement the information provided.

Heavy Civil Construction Earthwork is a specialized construction operation that relatively few contractors can perform on a largescale basis. It requires a vast inventory of expensive high-tech equipment and the knowledge and expertise to utilize them properly and efficiently. Therefore, nothing can take the place of "hands-on" experience and exposure. This course will introduce the reader to the subject matter, but the writer encourages all who wish to participate in this high-energy construction, to get out in the field and get "dirty".

Heavy Civil Earthwork involves Excavations (cuts) and Embankments (fills). When evaluating a project, quantifying the relationship between cuts and fills will be the most important factor in estimating, scheduling, and planning the construction. When a project's cuts are equal to the fills, it is referred to as a "Balanced" project. Owners can balance a project by allowing the contractor to place excess cut materials in "fattening" fill slopes or can provide for needed fill material by allowing over-excavation of the cut slopes. Projects that have more cuts than fills are considered "Waste" projects and projects with more fills than cuts are "Borrow" projects. To lower the cost of construction, and where available, owners can also provide locations outside of the main project site as a source of borrow material or a place to waste excess. If the owner does not have this ability, an off-project site will need to be located and paid to import or export the earthwork material.

Since embankments are man-made constructs consisting of known/controlled materials placed in defined locations, whereas, excavations are performed in existing unknown subsurface conditions, excavation earthwork is generally more difficult, has more risks, and requires more planning than embankment construction. Because of these difficulties the excavation subjects of the course will be more in-depth than embankments.

Whether it is earth, shale (or other soft rock), or hard rock, used to build a wide range of civil structures including airports, roadways, river locks, or dams, the projects will need some form of earthwork operations involving the movement of millions of cubic yards of these materials.

Excavation:

Excavation work probably provides the widest range of options to a project management team. Project managers, Superintendents, and Engineers consider these options when deciding on a method of operation. To be overly simplistic, asphalt paving work requires a paver and rollers, concrete paving a placer and paver, but with excavation work, there are several ways to go about the loading, hauling, and placing of the materials, each depending on the set of circumstances encountered. Do we use single engine scrapers, double barrel scrapers, big scrapers, little scrapers, self-loading scrapers, single push them, double push them, use self-loading scrapers with no pushing, or not use scrapers at all? Would an excavator and trucks be more suitable to perform the work?

These are some of the questions we must ask.

Suppose you had a project that required two million cubic yards of earth and rock to be moved from one large cut to be placed into 10 separate fill areas over a 5-mile area; What type of equipment would you use? To make a responsible decision, we would have to ask ourselves a few questions and compile a few more facts.

For instance, how much earth and how much rock? How hard is the rock, and do the specifications require it to be put at the bottom of the embankments before any earthen material is placed? How long are the hauls, and over what type of terrain? Are there traffic considerations or weight restrictions? This is all part of the Engineer's job to answer these questions, so that the Project Manager and Operations Manager can assemble the most cost-effective equipment spread for use. Some of this information must be known before bid submission, and some can be determined after.
Other considerations include Support of Excavation, Blasting, Sediment and Erosion Control, Drainage, etc…

Embankment:

Utilizing the same general materials as listed in the previous excavation section, Embankments are man made constructs, so the engineer is required to be more select in the material to be used. If a project generates a large amount of unsuitable material, a waste embankment or a non-structural portion of the required embankment may be set aside by the owner to utilize the unsuitable material, but in general, embankments are constructed in a controlled manner utilizing a controlled material.

Similar to excavation and mostly dependent on the type of material, the construction of embankments offers many options to the management staff for equipment and method choices. Are there select material requirements? maximum diameter of materials? If it's clay, do we need a sheepsfoot compactor? If its sand, do we have a water source? Have we maintained the haul routes for trucking? What is the maximum placement lift thickness? Etc.. All of these questions will be answered with different types of embankment operational needs.

excavation and embankments needed for Interstate construction project

Other Earthwork Items:

Some specialized operations will be discussed like support of excavation and shoring, and rock drilling and blasting. Other earthwork activities apply to both cuts and fills like: hauling materials, rough grading, fine grading, slope stabilization, topsoiling, and other protection/finishing operations which will be the final subject matter of the course.

Definitions

Soil (Natural) – Unconsolidated clay, silt, sand, gravel, and organic materials.

Backfill – Soil material placed to fill an excavation.

Topsoil – Soil materials used to establish and promote vegetation growth, containing necessary organic and chemical compositions.

Rock – Rock material in beds, conglomerates, boulders, unstratified masses, ledge, and bedrock, exceeding one cubic yard, which cannot be removed with normal excavation methods and equipment.

Borrow- Imported soil materials from off-site needed to construct embankment fills.

Contaminated or Hazardous Soil Materials – Excavated material containing quantities of substances that present potential hazards to human health or the environment when improperly managed and exceed allowable government standards.

Excavation (cut)– Removal of soil or rock material from above subgrade elevation or plan elevation and moving the material to a new location.

Structure Excavation or Embankment – Earthwork necessary for the construction of footings, walls, slabs, or other structures above or below existing ground surfaces.

Undercut Excavation – Authorized removal of additional soil or rock material below subgrade elevation or planned elevation and moved to a new location. Usually performed to remove unsuitable material.

Embankment (fill) – Soil or rock materials (natural or man-made) moved from an alternate location and placed in a controlled manner to raise existing grades to subgrade or plan elevation.

Subgrade – After completing excavation or embankment, the finished surface immediately below subbases, beddings, structures or topsoil.

Stockpiled Material – Excavated material temporarily placed and stored for future use, disposal, or treatment.

Compaction – Mechanical or material effort to make an in-place soil layer more dense, used to improve soil bearing capacity.

Grading- A treatment to the finished surface of an earthwork construct to a plan line and elevation within specified tolerances.

Hauling- Mechanical transportation of earth materials to an alternate temporary or permanent location a distance longer than can be moved by excavation operations, requires loading material into a transportation unit.

Dewatering- Removal of excess moisture from an earthwork activity by drying, pumping, draining, or other physical or chemical means.

Proctor- An ASTM test used to determine the optimum soil moisture content to achieve the maximum density at a specified effort of compaction.

Trenching – The construction of a long narrow excavation, usually deeper than it is wide.

Mass Diagram – A graphical representation of cumulative earthwork cut and fill volumes along a project alignment used to calculate optimized hauling routes to balance material usage within the alignment.

Support of Excavation – Temporary structures used to retain unstable soil conditions until permanent construction can be completed.

Various State and Federal specifications have been consulted to produce this list of definitions including: FHWA, NCDOT, MBTA, AREMA, and other DOT's.

Materials

Earthen Material — Plain and simple is "dirt". Although it will make a difference whether it is cohesive or non-cohesive material, activities of earthen materials are generally easier than those of rock. An important first step is to classify the type of material so the proper construction techniques can be chosen. Most owners define soils acceptable for reuse by one of the accepted soil classification systems such as the AASHTO (American Association of State Highway and Transportation Officials) or the (USCS) Unified Soil Classification Systems. Each of these systems, and there are others, have slightly different criteria and ways to label and group native soils. Next identify which soils are suitable or unsuitable for the project requirements. Lastly, identify the classification of the available suitable materials and their applications to determine the means and methods of excavation and embankment construction. Different equipment works better to move and compact different soils. For instance, a sheep's foot roller works well with cohesive soils, but is not worth much in non-cohesive soils. Likewise, you need plenty of water to compact non-cohesive soils, but you are usually trying to lower the moisture in cohesive soil placements.

Be careful whenever you are around soils classified as fat clays (PI greater than 50). Found in shades of blue or yellow, these soils, depending on the moisture content encountered, are most always difficult to load, haul or place.

Muck Excavation of Unsuitable Clay Material in a storm sewer excavation

Shale — is the intermediate of earth and hard rock. Contractors use "Shale" as a general term to include rock of low to medium seismic velocity. Therefore, most clay stone, mudstone, siltstone, and fine-grained caliches fall into this broadly defined category.

Shale can be useful to a construction foreman in many ways. It can be used to solidify a messy haul road, or to stabilize a wet fill. Some shales can broken down by the cutting edges on a dozer or scraper, but due to the varying hardness of this rock classification, many types of shale have to be "ripped" in place with a dozer tooth before being excavated. Others may even have to be "Popped" with a blasting agent. Determining whether this material needs to be ripped or not will factor into the load and haul equation.

Shale Excavation for Bridge Footing

Hard Rock- for our purposes is anything with a seismic velocity over 9000 fps. (Clue: Look in the Cat Performance Handbook). This cutoff point mostly means the rock is no longer rippable, and must be drilled and blasted or hoe-rammed. Whenever a rock cut is drilled and shot, the pre-splitting of slopes must be evaluated. Generally speaking, presplit is required on rock slopes steeper than 2 vertical to 1 horizontal, that are exposed to view by the traveling public.

Hard rock can have may uses on a project and can be an economic benefit to the contractor. Depending on the type, quantity, and quality of the rock, and the requirements of the specific project. A contractor can mobilize a portable crusher and manufacture aggregate products for sale or use, thus saving money from not having to purchase this `product" from a commercial source.

Cohesive Materials — Having an accurate proctor curve for cohesive materials is an absolute must. Due to variations in soil composition within the same cut, obtaining required densities when placing cohesive material in an embankment can become frustrating if proctors are not representative of the soil being placed.

Moisture content is usually a problem with most cohesive materials. Material of this classification usually need some drying, either in the cut or the fill, to achieve optimal moisture content as required by the proctor. This is achieved by use of disc harrows, dozer or grader ripper arms, or in some cases a jet dryer. It is important to minimize moisture problems caused by rain or snow on the incomplete embankments or unexcavated cuts. If surface water is not controlled the material may require re-drying efforts and re-compaction, or even replacement. There is little that can be done to control the rain and snow effects other than to keeping constructed areas well-draining and sealed at the end of each shift.

Non-Cohesive Materials — Problems with moisture in non-cohesive materials stem from not having enough moisture, as opposed to having too much. Especially with clean sands, large amounts of water will be needed if a compaction specification of 80% or more exists. Having a source of water readily available for high volume embankment operations can sometimes be a challenge. Excessive sun and wind can dry out materials below the optimum moisture content required by the proctor. If a free local water source is not available, irrigation systems or municipal water sources will be needed at an expense to keep this material acceptable.

Equipment

There are many different Heavy Construction Equipment manufacturers and many different types and models offered by each manufacturer. The basic and most widely used equipment pieces are: Dozers, Track Loaders, Wheeled Loaders, Backhoe Loaders, Hydraulic Excavators wheeled/tracked/mini/zero-turn/long-stick, Graders, Compactors, Trucks on/off road, Scrapers and Pans.

The Caterpillar Performance Handbook is a handy source of information pertaining to earthwork and equipment performance. It is updated every few years to reflect new model changes. The handbook can be obtained from most any Cat dealer.

DOZERS

DOZERS

Dozers utilize a large metal blade to push materials. The blade can excavate materials and then carry the material over short distances. It is utilized in both excavation and embankment operations. In an excavation the dozer can cut material to be pushed into its new location or into a temporary stockpiled location to be loaded and hauled by other more efficient equipment. In an embankment it can be used to spread materials dumped by hauling equipment at the fill site. Dozers can be tracked or wheeled depending on the project requirements. Wheeled dozers are faster but tracked dozers are move powerful/stable. Dozers with tilt-adjustable blades can rough grade finished slopes and riding surfaces of cuts and fills.

TRACK LOADERS

By Kevin M Haddocks, U.S. Navy - http://www.navy.mil/; VIRIN: 050711-N-2448H-880, Public Domain, https://commons.wikimedia.org/w/index.php?curid=9969729

WHEELED LOADERS

LOADERS

Similar to the previously mentioned Dozers, Loaders can be track loaders or wheel loaders. Because of their large bearing surface area, track loaders are more stable and powerful, and they can traverse rougher terrain. Wheel loaders are faster than track loaders, but their load is distributed over a much smaller surface making them less stable and unable to cross soft or rough obstacles. Loaders have a large bucket mounted in front that can be filled with materials and carried over much greater distances than dozers. Loaders can be equipped with hoisting hooks for lifting heavy weights. They can also use the blade of the bucket as a cutting edge like a dozer for grading by “back-blading” a surface.

EXCAVATORS

Excavators are primarily used to dig and load soils and rock. Other than moving and spreading materials short distances, there use in embankment construction is limited, but they are an essential piece of equipment for any excavation operation. The excavator has a digging bucket attached to an articulating boom or "arm" that is mounted to a housing that can swing 360 degrees. There are many variations in buckets and booms that can be utilized for every excavation need. Two basic types of excavators are classified by the undercarriage tracked and wheeled. Because the excavator can operate 360 degrees, wheeled excavators are equipped with stabilizing outriggers when excavating or loading perpendicular to the wheel line. Tracked excavators have different load ratings for perpendicular work but are stable for working in all directions.

TRACKED EXCAVATORS

WHEELED EXCAVATORS

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MINI EXCAVATORS

SPECIALIZED EXCAVATORS

Excavators can be equipped with buckets ranging from heavy duty rock ripping to special shaped grading buckets for ditch lines. Boom lengths can be long reach, or mini depending on accessibility demands. New “zero turn” excavators are being utilized more frequently for congested urban roadway and commercial projects because the housing is no wider than the track footprint. A “zero turn” mini excavator is shown in picture.

BACKHOE LOADERS

By Shaun Greiner from Creve Coeur, United States of America - CAT 023, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=6104060

BACKHOE LOADERS

Backhoe loaders are “do-all” pieces of equipment found on most earthwork projects. The backhoe/loader combination allows it to excavate, load, haul, place, and backfill an operation. The loader bucket is mounted on the front end and the excavator bucket on the back so this piece of equipment can, on a limited basis, take the place of two separate machines. The large tires of the tractor allow it to operate over rough terrain.

GRADERS

MOTOR GRADERS

A motor grader has a blade located between the front and rear axles. The most common function of a motor grader is to level ground in preparing roadway layers, whether the final riding surface of a dirt road or intermediate stone or soil grades. They can also use their blade like a dozer to cut and push small amounts of materials to trim the final surface grade.

SCRAPERS

SCRAPERS

Self-loading-hauling units that combine the ability to excavate a surface with a blade, collect the material, haul it to a new location, and dump/spread the material for use. The front of the scraper is a tractor that pulls the rear bowl of the machine. The bowl is wedge-shaped to cut & force excavated material into it. Once full, the bowl raises so the soil can be transported without spilling and then lowered again to dump and spread. Scrapers can be self-propelled or can be pushed from behind by a dozer.

OFF-ROAD HAULING TRUCKS

By Harry Bush - http://www.public-domain-image.com/public-domain-images-pictures-free-stock-photos/transportation-vehicles-public-domain-images-pictures/trucks-public-domain-images-pictures/caterpillar-dump-truck.jpg, Public Domain, https://commons.wikimedia.org/w/index.php?curid=24920191

ON-ROAD TRUCKS

ON & OFF-HIGHWAY TRUCKS

Trucks are used to haul earthen materials over long distances. Government vehicle restrictions regulate the use of trucks on public roads. Permitted highway trucks are used if the hauling requires the use of public roadways. Load restrictions require multi-axel dump trucks for large volumes/weights of materials hauled. If the haul routes are limited to the project site or private property, off-highway trucks may be used. Off-highway trucks can carry heavier loads which translates to more material per trip. Off-highway trucks have larger tires with larger bearing surfaces so they can cross rough terrain and soft materials. Articulated trucks are one type of off-highway truck and are ideal for hauling on construction sites. The cab of the truck (or tractor) is separated from the bed with an articulating pivot. The pivot makes it easier for the truck to travel on the rough terrain and makes them easier to steer with the heavy loads, but it also makes them less ridged allowing them to easily tip over. Only experienced drivers should operate articulated trucks.

SMOOTH DRUM ROLLERS

COMPACTORS

Possibly more than any other earthwork equipment, compactors are chosen specific to the type of material being compacted. Tandem vibratory rollers and rubber tired pneumatic rollers are used to compact asphalt pavement. A sheepsfoot landfill compactor is the best fit for trash and waste. Soil compactors are used for embankments. For most earthwork compaction, smooth drum and sheepsfoot compactors with static and vibratory rolling capabilities will be needed.

SHEEPSFOOT ROLLERS

WALK-BEHIND ROLLERS

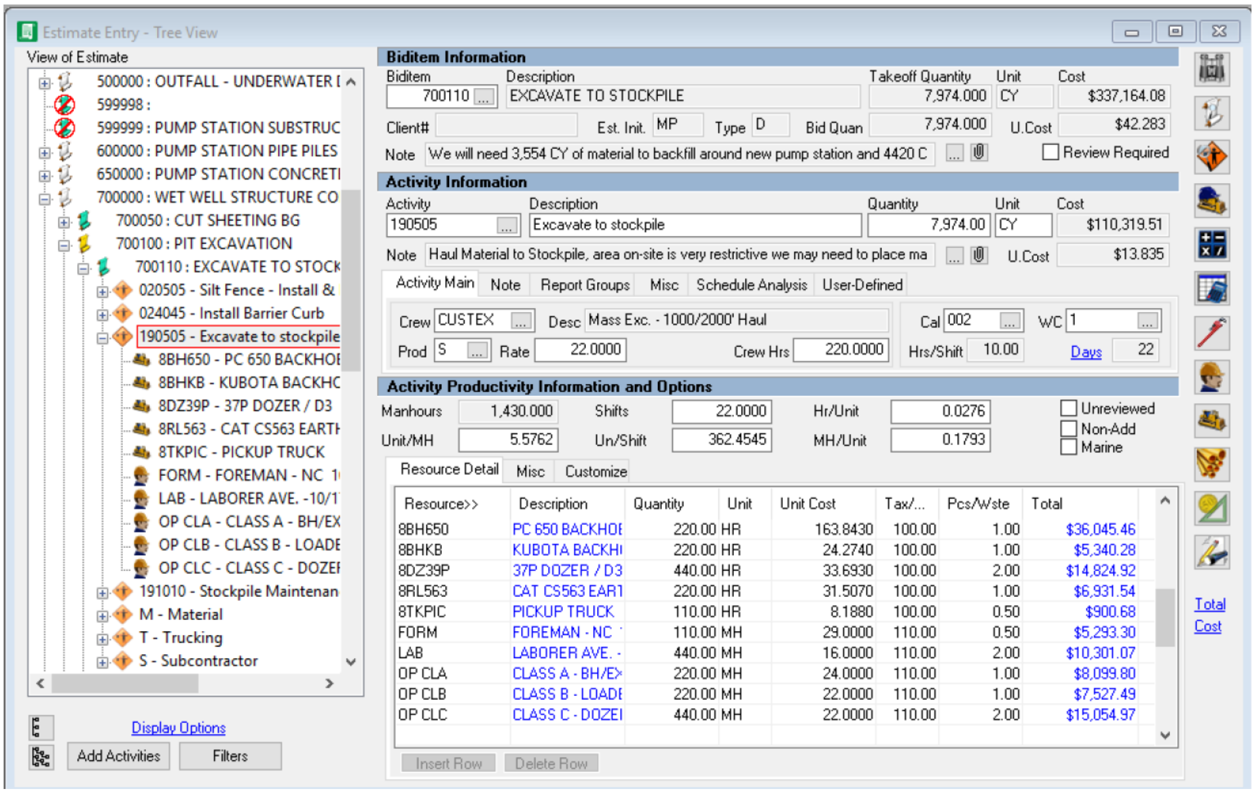
Earthwork Construction Engineering Roles:

Engineering large earthwork projects are very involved and require many disciplines. Designs need to consider geotechnical issues, drainage issues, final surface design (whether it is a roadways line and grade or a structure's foundation), environmental concerns, and owner's economics to name a few.

The purpose of this course is to help engineers who design the above items understand the processes of construction to make their designs safer, more timely, cost effective, and with better quality, and to identify the roles of the Construction Engineer in these projects.

The construction engineer supports the construction team in executing their activities and it starts with estimating the work and developing a work breakdown structure (WBS). The WBS is used for scheduling activities and developing a budget. Next the project requires a work plan to develop equipment, materials, and labor means and methods. This helps the crews meet the schedule, budget, quality, and safety requirements. While executing the work, quality control testing and documentation, survey and engineering calculations, schedule updates, and quantity tracking for budget are engineering responsibilities that keep a project on track.

Estimating Earthwork
A whole course could be dedicated to earthwork estimating. Some items include: Interpretation of cross-sections for average end areas, and for layers of the different materials; from stripping topsoil & undercuts, to select materials for structures and utilities. Understanding the subsurface information provided from borings and test pits. The use of contour lines and 3-D imaging and evaluating their accuracy depending on whether the surfaces were determined by aerial photographs, scanned by drones, or manually surveyed by conventional and GPS readings. Creating a Mass-Diagram for balancing quantities and determining efficient movement of materials. From these items, the estimator must then determine crew sizes and equipment types for best handling the identified materials.



A screenshot of an estimating software program showing a 7,974 CY excavation operation of the WBS

It should be noted here that a big part of good earthwork estimating is utilizing good historical data from similar current and past projects. Past records of lost time due to equipment problems and weather are critical to establishing factors for future work. As examples, knowing the pounds and types of explosives used for successful blasting of different types of rock strata, the actual average load size and cycle times for various equipment used, and the number of units in a spread will all help with pricing similar future work. Remember, just having the unit cost of an operation is not enough. In the previous section it was stated how variable earthwork projects could be. Material and labor prices can change from year to year & job-to-job, estimators need to detail the specifics that back up their unit prices.

For large earthwork estimates, the team should develop a project Mass-Diagram. The Mass-Diagram is a graphical representation of cumulative earthwork cut and fill volumes along a project alignment. The volumes are used to calculate optimized hauling routes in order to balance the material usage within the alignment. It is the "Road Map" to tell you where the excavation and embankment are located, where the material is going, and what it is made of. It will also show the haul distances involved and any obstacles in the way of the haul, such as rivers or cross-roads. The mass diagram will detail if the project is earthwork balanced, or whether it requires "borrow" or "waste". If either is needed, the mass diagram will tell you where the most opportunistic location is to either borrow or waste. This will help in evaluating offsite sources so arrangements can be made with adjacent property owners and identify the best means to move forward.

Developing a Work Plan

After award of a successful bid, the construction engineer can utilize the WBS created by the estimators to develop the project's schedule and budget, and can identify the labor, equipment, and material needs for the construction activities.

Important considerations when developing a work plan:

The number one key to success when working with an excavation and/or embankment project is Dry Weather. Although rock and shale are less susceptible than pure earthen materials, and sands do need moisture to aid in the compaction effort, dry weather will help more than any other single ingredient to make a successful earthwork project. That is why knowing the location of the project and time of year the earth work will be performed, is so critical to a project schedule, quality, safety, and budget.

Special attention needs to be paid to the lift thickness of embankments required by the contract documents. Generally, earth lifts are 6"-8" in depth and rock lifts are 12"-24" in depth. This information is not only important to know in order to help size the equipment needed, but also to size the material that will be placed in that lift.

Likewise, compaction specifications also need to be reviewed prior to the start of work. Remember: Generally speaking, earthen materials shrink when being taken from an in-situ cut to a compacted fill. That means you need more than 1 cy of earth from the cut to make 1 cy of compacted earth embankment (Generally use a factor of 15%). Rock on the other hand swells by as much as 15%. Therefore, you can expect 15% more compacted fill from a solid rock cut. Shale like materials, yield about a cubic yard of embankment for each cubic yard of cut. This information will help in balancing the materials from cuts to fills and if a Mass-Diagram was prepared by the estimators this information may already be available for field use.

Quality Control and Submittals

The contract plans and specs will detail the acceptance criteria for the earthwork construction. They will detail how to classify the work and the submittals and testing requirements needed for acceptance of the work.

Other than determining the limits of construction and establishing the lines and grade shown on the contract drawings, mass excavation operations do not require many submittals or quality control tests until subgrade and finish grade operations occur. Similar to excavations, embankments will require limits of construction identification and establishing the lines and grade shown on the contract drawings, and subgrade and finish grade quality control and testing. But unlike excavations, embankments will also require submittals, and quality control testing and inspection throughout the operations.

Each material used for embankment construction will require submittals. Identifying the source of the materials (even onsite excavation materials) will be necessary information for the owner and QC staff. The specifications will detail the laboratory tests needed for each product, which at a minimum, usually requires soils gradation testing, atterberg limit testing, and standard or modified proctor tests (Specialized materials may require additional tests like internal friction angle, ph levels, or amount of organics). The specifications will also detail the types and frequencies of field tests needed for acceptance of the embankment as construction progresses.

As previously stated, embankments are controlled constructs made from controlled materials. Embankment construction should begin from the lowest elevation in an area and progress upward. Materials should be placed in horizontal layers not exceeding 8 inches in uncompacted depth. Each lift should be tested for compaction as a percentage of maximum density and optimal moisture content compared to the submitted laboratory proctor tests representing the material. General acceptance criteria would be: Relative compaction > 95% and Moisture content within +/-2% of optimum. Construction of fills and embankments during freezing weather should not be done because fill materials should not be placed on frozen surfaces, nor should frozen soil materials, snow, or ice be placed in an embankment.

The compaction testing is usually performed with a Nuclear Density meter. Maybe these aren't the latest in technological tools for measuring density, but they are still the mainstay of the industry. Originally developed in the 1950's, they provide a quick, accurate determination that is accepted by most owners. It is relatively easy to change proctors, and readings can penetrate a full 8" lift.

(a nuclear density gauge (shown above) emits radioactive particles and measures the number of particles that pass through a substance in a given period of time to determine the density of the in place material)

Safety is a major concern both in using and storing the Nuclear Meter. Strict guidelines are established by federal and State agencies, which include licensing, qualified users, and monitoring of individual exposure by use of a ray-absorbing badge. The film on the monitoring badge needs to be evaluated at regularly established intervals to ensure user safety. Any questions about the nuclear gauge or its proper use, transporting and monitoring should be directed to your Safety Department.

Should the lifts consistently fail specifications when compared to their appropriate proctor, compaction methods need to be altered. The changes in compaction methods can include: changes in compaction equipment, reduction in uncompacted lift thickness, increase in number of passes, and better moisture control. The quality control engineer can provide feedback to the project team on which changes would be most effective.

Both Excavations and Embankments will have Subgrade Quality Control testing and inspection. Especially in subgrades constructed in excavations and as directed by the Engineer, the subgrade may be proof-rolled by a loaded dump truck, or other suitable rubber-tired equipment acceptable to Engineer. The number of passes of the proof roller will be as needed to sufficiently cover the prepared area. If the subgrade moves, ruts, or pumps during the proof rolling, additional work will be needed before acceptance. This may include additional compactive efforts, but may also include undercut excavation to remove any questionable materials to be replaced with a bridging lift as determined by the engineer. Any soft, yielding, or otherwise unsuitable material should be removed and replaced with compacted material
.
The subgrade may be further tested by a drop hammer to determine bearing capacity and will also be tested for line, grade, smoothness, and lift thickness (if a specified surfacing material is required) to be sure the subgrade is within construction tolerances.

Quantities & Record Keeping
An Owner can pay for earthwork items in many ways, each way will require a different method of tracking quantities. Additionally, for historic data and production evaluations other quantities will need tracking for internal corporate and project use.

Most earthwork items will be tracked by the cubic yard. This quantity needs to be computed accurately using cross-sectioned end areas or surface comparisons from 3-D Model volumes. When/if digital original ground data is not available, the original and final ground of the project needs to be surveyed to generate the surface models or cross-sections so quantities can be computed.

Realizing the final ground shots are available only at the completion of an area, interim data must be generated to allow for accurate weekly costs or monthly payment submissions to be generated. If you do not have the means to do this electronically, or by taking interim survey shots, then calculating quantities from hauling unit load counts is an acceptable approximation for evaluating partial earthwork quantities, but they are rarely acceptable for determining final quantities. Using load counts to account for quantities, even just for interim payment, can be tricky.

Once a hauling spread has been determined, look in a Equipment Book and determine the capacity for the material being hauled. Agree on a capacity for each size-hauling vehicle used. Then approximate about 85 % of the number for record keeping. This is a good practice for interim quantities because sometimes load counts are inflated on the timecards, or the loader/backhoe operator isn't getting the maximum load on the hauling vehicle. Loads of rock contains a lot more void space than a similar load of soil. The load count capacity for rock should be approximately 5% lower than the same size vehicle carrying a load of soil.

Another good practice is to not over report the quantity moved by load count measurement. The worst feeling in the world is to have to tell the Project Manager that the costs are 20% greater than projected because the final survey calculations produced a lower quantity than the load counts did.

Typical quantities tracked on earthwork projects include: CY's Unclassified Excavation (may be broken down by type whether "dozer push", "mas-excavation", or "light cuts and boxing"), CY's Hauled by distance (to waste, to stockpile, to embankment), CY's of Embankment Placed, CY's Undercut & Backfill, SY's of Fine Grade or Subgrade, CY's of Topsoiling or SY's of Slope Prep, etc..

Survey & Field Engineering

Whether with GPS rover packs or traditional surveying instruments, baseline control and Plan Grade Line (PGL) line and grade, will be staked-out by the survey crews.

Establishment of the centerline alignment and profile grade is the critical first step of the earthwork to be performed.

Foremen will need something to correlate their plans to the layout stakes provided by the survey crews. The field Engineer can make up a simple sheet which gives offset and vertical height dimensions from centerline for each grade point of a cross-section. Points may include breaks in cross-slope, edge of pavement sections, top of cut/fill, limits of clearing, and ROW limits. Any important changes in the typical section that the grade crews need for construction of the cut or fill.

Usually, the earthwork crews need only a few points to get started in big cuts, or big fills. Toe-of-slope or limits-of-disturbance points with slope information are all that is needed to “floor-in” embankment or “hog-out” an excavation. However, as the construction gets closer to final grade elevations, the foreman in the field may need help converting layout to an actual profile grade.

Grade sheets, or "cut sheets" as they are also commonly called, provide just that. They provide the grades (or cuts) needed to properly slope the roadway. Grade sheets are prepared by the field engineers to provide the cut or fill from PGL at each break point, transversely across the roadway section, at each 50-foot station. The sheets provide the horizontal distance to and vertical distance from the PGL.

The most important general rule that should be followed on a road job is to work from the design profile or baseline grade (PGL). To avoid misunderstandings; All earthwork "grade sheets" needed to construct the project will be calculated from the profile grade at that particular station.

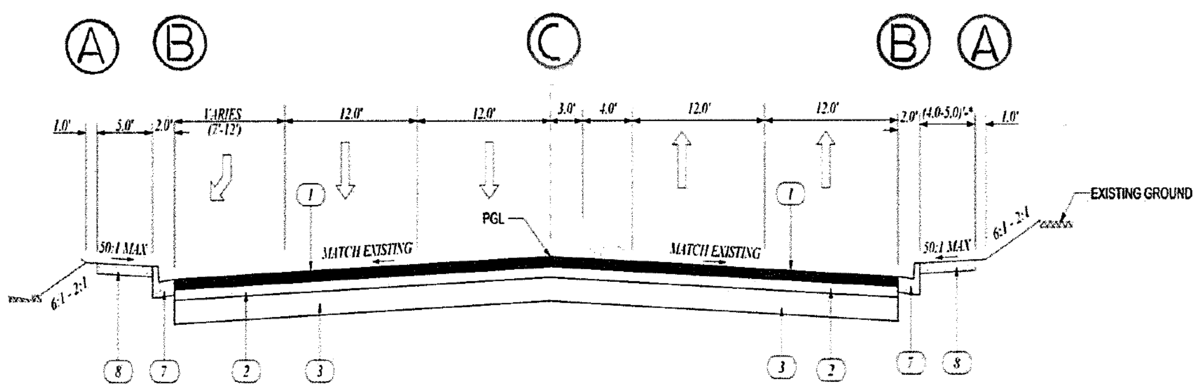
Surveying & Engineering technology and automated equipment have made grade control more available to the field crews. But even though there are computer programs that can perform the long, redundant math calculations in seconds, and survey rover packs with project models loaded that can instantly locate any given point or layer on a project, it is sometimes important to explain and show certain engineering documents the good old fashion way. Grade Sheets are one of those documents. Many plan conflicts, errors, and omissions have been caught and RFI's written from the process of creating grade sheets. At the very least it forces a field engineer to review and understand the entire project from start to finish.

Grade sheets are very repetitive for straight roadways of constant width but can get very complicated in curves and intersections with differing superelevations and shoulder breaks or median islands. A common mistake when creating grade sheets in areas like these is trying to get too much information on one sheet and having a resultant sheet that is too confusing to work with. Granted, it's nice to see everything on one page, but use some sound engineering judgment as to what is enough and what is too much.

The table and accompanying figure provided on the next page show a simplified grade sheet. The information is provided for five stations along an alignment. In the center of the table is the profile grade that we have been referencing. To the left and right of centerline lists the offset distance of select pavement breaks with the height difference (plus being higher and negative being lower) of that offset point from Profile Grade. Depending on the section's relationship with PGL, there could be 5 for more offset and corrections to the left and to the right, or there may be only one. It all depends on the number of slope variations in the typical section you are constructing. Elevations, cross-slopes, and layer thickness would also normally be provided but were omitted in this table to provide a simpler representation.

Always put the date and revision number, sheet number (x of xx), and project location on all sheets, and make a listing of who has received them. If a mistake is found or a revision is necessary, REISSUE ALL sheets and make sure the date and revision number are changed so everyone can tell which is the most current. You will be surprised the number of times the wrong sheets have been used in the field. The term "didn't know this was changed" isn't very comforting when a half-mile of grading is wrong.

Lastly, include a "Typical or Key Sheet" to all grade sheets as a visual representation for the data provided. The typical sheet shows just that, the typical section of the earthwork being constructed from the grade sheet. It should label the location of each "point" that data is given on the grade sheet. The location of each point should be clearly identified on the typical section that you attach to the grade sheet. Make sure the typical section is clear and legible. As an example, (A) could be top/bottom of slope (cut or fill), (B) could be edge of pavement, an (C) could be PGL, as shown in the below simplified example.



Station		Offset Lt	o/s distance	Offset Rt.		Station
			height from PGL			
	A	B	C	B	A	
12+00 lt	-44.00 / -0.08	-36.00 / -0.72	0.00 / 0.00	+31.00 / -0.62	+38.00 / -0.04	12+00 rt
11+50 lt	-43.50 / -0.07	-35.50 / -0.71	0.00 / 0.00	+31.00 / -0.62	+38.25 / -0.03	11+50 rt
11+00 lt	-43.00 / -0.06	-35.00 / -0.70	0.00 / 0.00	+31.00 / -0.62	+38.50 / -0.03	11+00 rt
10+50 lt	-42.50 / -0.05	-34.50 / -0.69	0.00 / 0.00	+31.00 / -0.62	+38.75 / -0.02	10+50 rt
10+00 lt	-42.00 / -0.04	-34.00 / -0.68	0.00 / 0.00	+31.00 / -0.62	+39.00 / -0.02	10+00 rt

Support of Excavation

The term " Support of Excavation " covers a wide range of procedures to shore up or support the vertical or near vertical faces of an excavated area. It may include wood planking, metal forms, unbraced or braced steel sections, soil nailing, tie-backs, or shotcrete surfacing.

Anytime an excavation is deeper than 5 feet there are potential problems. OSHA law allows that an unsupported vertical surface must meet the following criteria:

- **Less Than 5' in Depth:**

Excavations may be made with vertical sides unless there is a potential for cave in. If the potential for a cave in exists, shoring or sloping sufficient to control any hazard should be used.

- **Over 5' but Less Than 20' in Depth:**

Excavations must be classified by a competent person and either benched or shored as required by OSHA for the identified classification.

- **Over 20' in Depth:**

A registered professional engineer licensed in the state where the work is to be performed must design protective shoring or sloping.

- **In Stable Rock**

If the excavation is entirely in stable rock, the excavation may be made with vertical walls. Note: Rock which is not stable, should be considered a Type B soil.

Excavation safety is a complicated subject and will not be addressed in this course. Trench collapse is one of the leading causes of death and serious injury to construction workers. A separate future course may review the OSHA guidelines for excavation safety requirements. For this course, NEVER enter a trench that has not been approved by the contractor's safety program, and NEVER enter a trench that does not meet OSHA access and shoring requirements.

Please reference OSHA 1926 Subpart P Excavation
1926.650 Scope, application, and applicable definitions

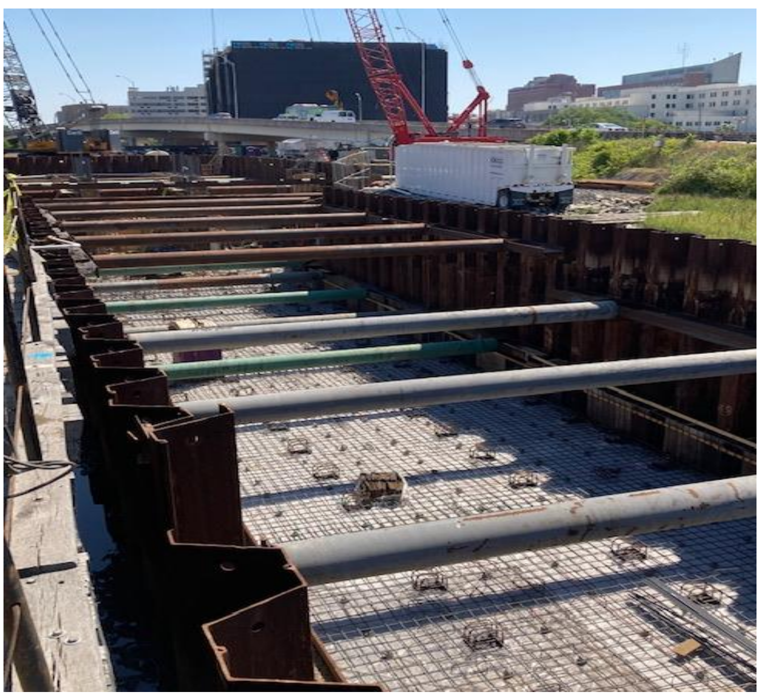
Types of Support of Excavation

For major excavations requiring support, two of the most common forms of SOE are discussed below. Although there certainly are several other methods in use, these are two of the most widely used and accepted methods in the industry. Like so many other parts of our work, each has positive features, and each has negative drawbacks.

Professional Engineers design these types of structures taking into account lateral earth pressures and surcharge loads in order to size the support members, bracing, and toe embedment. There are many courses that detail the structural and geotechnical design for the support of excavation.

Steel Sheeting

Either braced or unbraced, steel sheeting is one of the most costly of supports used. Typically consisting of interlocking, readily available mill-rolled steel members such as PZ22 or PZ27, the individual pieces are locked together then driven into the ground with one of several different types of pile hammer. Although not suitable for all soil types or conditions, steel sheet piling can provide significant support for controlling movement or undermining of existing buildings or foundations. It can also be used efficiently to help control ground and surface water seepage problems.



When placing sheet piling at right angles to each other or when suddenly changing the direction of the sheet piling, one of a variety of sheeting accessories must be used to lock the sheets together. Corners of 45°or 90°are common, along with "wye" connectors of various angles.

Solder Pile and Lagging

An effective and relatively cheaper form of SOE than the steel sheet pile is the solider pile and lagging method. Typically, the solider pile (any H or W pile meeting design criteria) is augured or driven into the ground vertically at 6 to 8 foot intervals. Wood planks or steel plates are then set between and behind the flange of the vertical pile as the excavation progresses downward.

Although cheaper, easier, and more adaptable to varying conditions, they are harder to install in situations requiring tight tolerances and offer very little in controlling surface or ground water seepage.

Layback

If possible, it is desirable to layback slopes rather than install the costly support of excavation we just talked about. This is by far the most economical means of complying with OSHA. Unsupported slopes must be a minimum of 2 horizontal to 1 vertical unless the competent person determines a steeper slope is allowed by the OSHA Standards or a professional engineer designs and stamps, a slope with a steeper angle.

Blasting

Blasting is both a science and an art that needs to be supervised by skilled, licensed professionals. Many things have to be calculated into a successful blast, all based on the type of rock and the desired end result. For Instance, the proper combination of drill hole diameter and drill hole pattern & spacing needs to be determined in order to produce an 18", 24" or 36" end product. The end product size is important if the rock needs to be put into a certain maximum depth of lift fill, or whether it will need to go through a certain size crusher. There are several types of blasting agents that are used. Primer cord is often used in presplit or line drilling applications. Bulk fertilizers (Ammonia Nitrate and Fuel Oil (ANFO)) are used in dry holes where mass production and less specific control are required. Underwater gels are used in wet holes. Each manufacturer has brand names such as Dupont's water gel "Tovex", that each of the different product lines are called.

Along with the explosive itself, one would need a blasting cap to ignite the sequence. Generally, "delays" are used on the blasting caps to allow for split second timing differences between ignitions of the holes. Typically, all holes along row 1 of a rock face would have a zero delay, row 2 would have a delay of 1, row 3 a delay of 2 , etc etc. Obviously it is not always as simple as this, depending on the results you need to obtain. The next pictures show drill patterns loaded and ready to blast.

Always remember that when blasting is needed on a project record keeping and fulfillment of state and local licensing requirements is a must.

Earthwork Finish Construction Items

Subgrade

Subgrade, plain and simple, is the top of the dirt. Subgrade operations include getting the top of the dirt, excavations or embankments, close enough to required grade to allow for placement of the more expensive final layers of construction. Subgrade accuracy is important so the materials of the next layers can be controlled and placed efficiently.

Bladed equipment like dozers and graders are used to trim the subgrade. Stringlines are used to make sure the trimming is within tolerance. Lastly, final compaction tests are performed to document the quality of the constructed surface.

Fine Grade
Fine grade is the effort needed to complete subgrade. Each intermediate lift of embankment is spread, bladed, and compacted to a grade which is usually arbitrarily dictated by the lift thickness. However, the final lift of material excavated or placed (as described in the previous section "subgrade") will require the final fine-tuning of the grade immediately below the first course of pavement, so that the yield or waste of the more costly pavement is kept to a minimum. This fine-tuned trimming is referred to as "fine-grading."

Sediment & Erosion Control

When performing earthwork construction activities an engineer must be aware of sediment and erosion control requirements for environmental protection. Sediment and erosion control considerations are the subject matter of many publications and courses but have been standardized by most public agencies by Best Management Practices (BMPs) specifications and details. This course mentions sediment and erosion control as a necessary construction activity associated with earthwork but is not detailed sufficiently to cover this important operation. Below is a section from NCDOT's publication that can be used for reference should the reader need more information regarding sediment and erosion control construction.

As an example, NCDOT states: "*BMP's are activities, practices and procedures undertaken to prevent or reduce water pollution. They are sometimes categorized as: preventive measures which are actions or techniques to eliminate or reduce pollutants at the source, or control measures which are means to remove or reduce concentrations of pollutants from the runoff*." They also provide a compendium of BMPs developed as a result of the adoption of state regulations addressing protection of water supply watersheds, and they present the policies and guidelines followed by the North Carolina Department of Transportation (NCDOT) in planning, design, construction, and maintenance of the State highway system in their 1997 document Best Management Practices of Surface Waters. This document serves as a condensed listing of BMPs and states in the Introduction: "*The reference listing directs the user to a source of further guidance in requirements or detailing of the Best Management Practices. While the document began as a response to water supply regulations, the need to protect other sensitive surface waters was recognized and the BMPs were expanded to address all surface waters. All state highway projects are also subject to the rules and regulations established by the North Carolina Sedimentation Control Commission, which is responsible for the implementation of the Sedimentation Pollution Control Act of 1973. It should be noted that highway projects near wetlands, sensitive waters, trout streams, etc. are subject to regulatory review and permitting by various state and federal agencies, including the U.S. Army Corps of Engineers, the North Carolina Department of Environment, Health and Natural Resources (DEHNR) and the U.S. Environmental Protection Agency. The primary goal of Best Management Practices is to prevent degradation of the states surface waters through the location, construction, and operation of the highway system. Therefore, the BMPs stated herein reflect actions that should be taken in the course of all highway operations at all locations, including water supply watershed areas. The Department of Transportation shall use these BMPs consistently on all projects, as applicable. While all measures listed herein are not applicable to every highway, those that are will be incorporated into each project development to the maximum extent practicable. The most stringent application of the BMPs would be expected where highway projects could affect environmentally sensitive waters, such as; Water Supply Watersheds, Trout Waters, High Quality Waters and Outstanding Resource Waters. The BMPs serve as general guidelines, and will result in acceptable protection of the states surface waters when used in conjunction with other North Carolina Department of Transportation's Standard Design Guidelines,* *Specifications, Design Drawings, and Sediment and Erosion Control Program Requirements*."

All earthwork projects are subject to similar standards and guidelines for safeguarding the environment and waters from impacts due to earthwork activities.

Conclusion

This introduction is a brief overview of the many operations of earthwork construction. Future courses will be written for specific sections of this course to provide a more in-depth review of each type of operation. At large scopes, this construction is very specialized and no matter how in-depth the courses are written, there is no substitute for experience. Many specialty subcontractors and suppliers offer onsite consulting services as a supplement to a project's construction staffing. To organize a new construction project, engineers and managers should strongly consider these additions as well as the support of an experienced construction engineering firm. The consulting experience will help train the project personnel, troubleshoot problems, and give confidence to the owner. Additionally, a well-structured quality control program is a must. Identification, control, testing, and approval of materials can mitigate unaccounted errors and can have significant impacts to cost, schedule, and **SAFETY**.

Lastly, safety must be a constant focus of every operation. Working with extreme heavy equipment in different environments requires safety diligence from every stakeholder Please be safe.

Fun Facts from Internet

- Tallest embankment Dam in the world – Nurek Dam in Tajikistan is 984 Ft tall and contains 70.6 Million CY of material … Google Search Information
- Tallest Embankment Dam in US – The Orville Dam in California 770 ft tall … Google Search Information
- Deepest hole dug – 7.6 miles in Russia … Business Insider.com
- Deepest Excavation – 1 mile deep 42 Acre surface area Kimberley Diamond Mine South Africa … Business Insider.com
- Largest Excavation – 11 Billion CYs Chile … Business Inider.com
- **And in Utah, Bingham Canyon is the largest man-made excavation in the world. It's about 4,000 feet deep, and stretches almost 3 miles wide.**

References:
Trench Safety: Code of Federl Regulations CFR Part 1926 and Related Standards

Sediment and Erosion Control: North Carolina Department of Transportation (NCDOT) 1997 document Best Management Practices of Surface Waters

As previously stated, Various State and Federal specifications have been consulted to produce this list of definitions including: FHWA, NCDOT, MBTA, AREMA, and other DOT's.

Wikimedia Photographs have been used and cited to supplement the equipment section of the course

