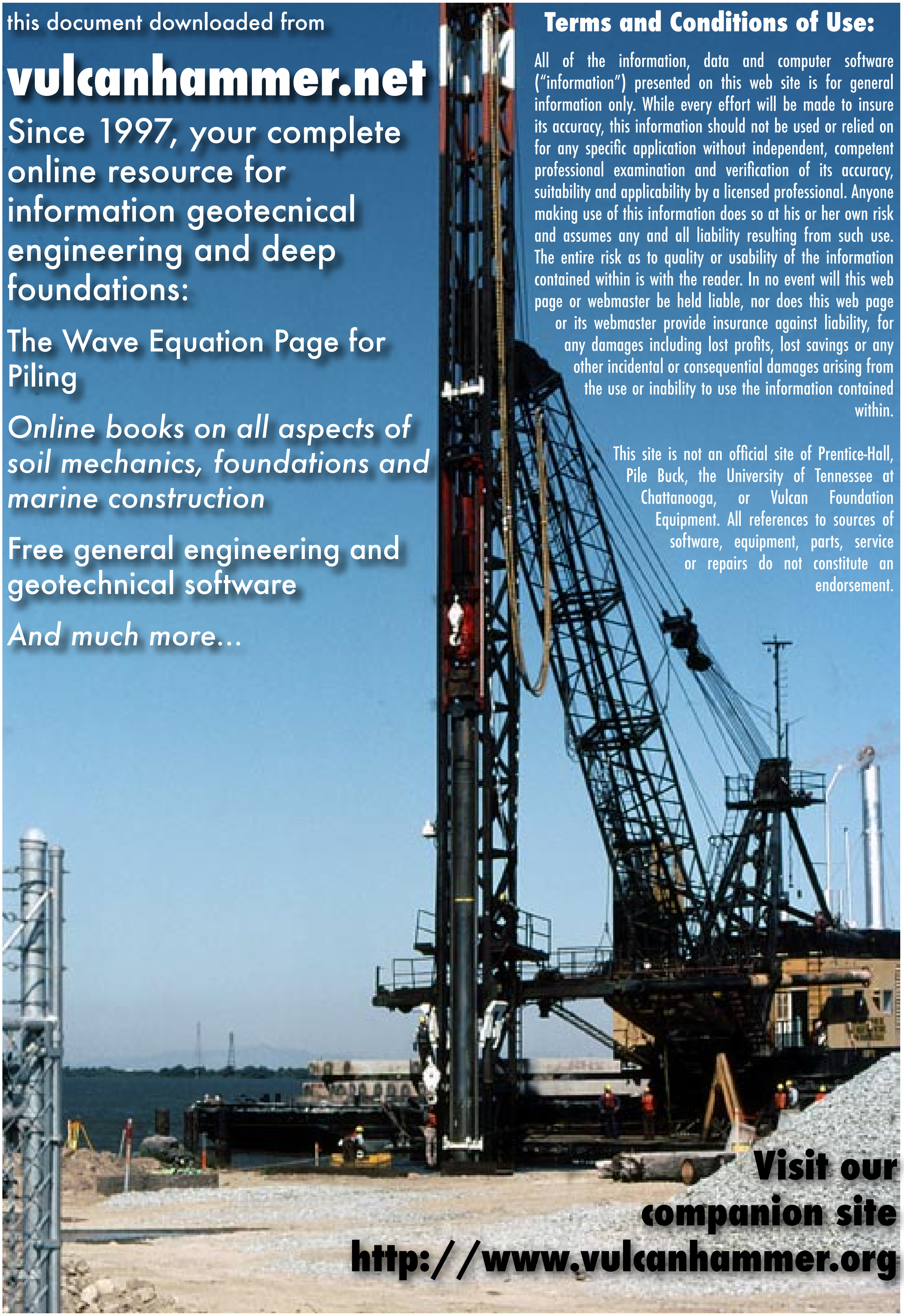


ENCE 461
Foundation Analysis and Design

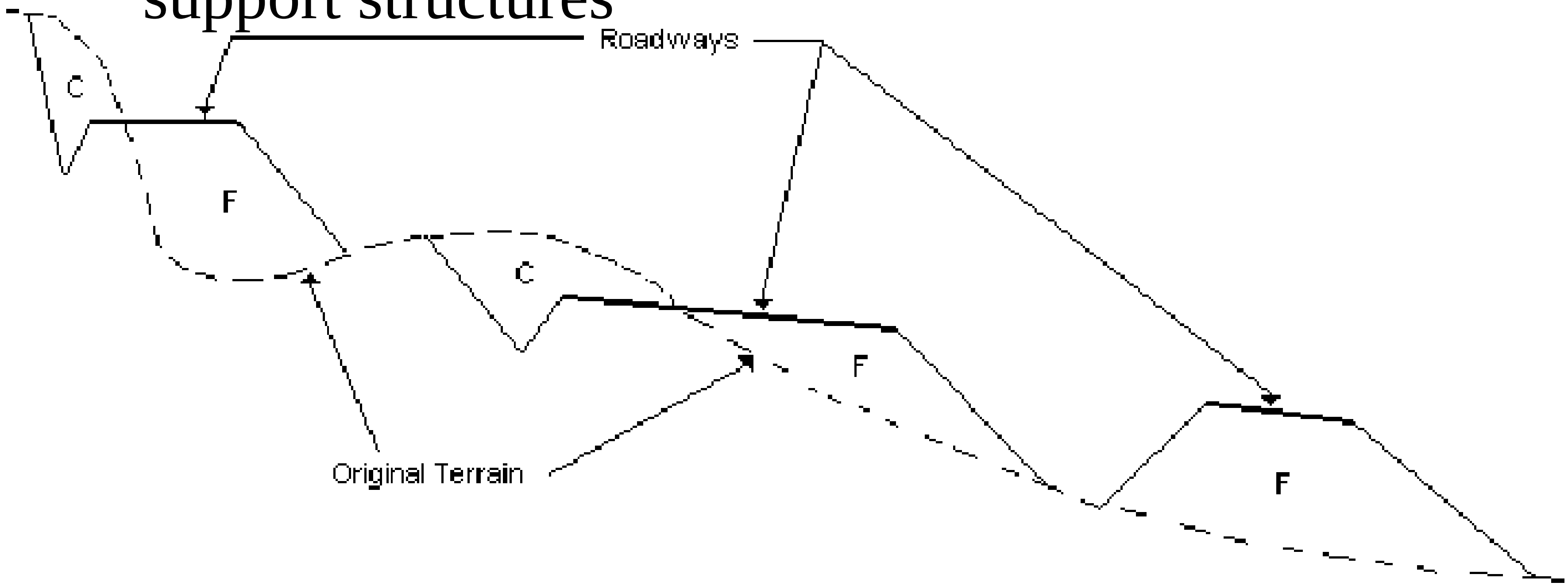
Soil Improvement

Overview of Soil Improvement

- Excavation, Grading and Compacted Fill
  - Soil movement and placement
  - Soil compaction
- Soil Improvement (other than Compaction)
  - Precompression
  - In-situ densification
  - In-situ replacement
  - Grouting
  - Stabilisation using admixtures
  - Reinforcement

Overview of Earthwork and Compaction

- Objectives of earthwork
  - To move the soil where it is needed
  - To improve the quality of the soil so that it will support structures



Objectives of Earthwork Construction

- To change the ground surface from some initial configuration to a final configuration
  - The final configuration is generally defined by a grading plan
- Earthwork must not create slope stability problems, either temporary or permanent
- Additional objectives of compacted fills
  - Fills must have sufficient strength to support both their own weight and external loads, such as foundations or vehicles
- Additional objectives of compacted fills
  - Fills must be sufficiently stiff to avoid excessive settlement
  - Fills must satisfy the first two requirements even if they become wet
  - Fills for the cores of earth dams or liners for sanitary landfills must have hydraulic conductivity low enough to restrict the flow of water
  - Fills for bases of pavements must have hydraulic conductivity high enough to enable drainage of the roadway
  - Fills should not be frost heave susceptible

Construction Methods and Equipment

- Historic methods
  - Large earthmoving and compaction projects were possible in ancient times, but required a great deal of labour and time to execute
    - Soil compaction was known in ancient times; in the Roman world, large logs (with handles and, in some cases, iron shoes) were simply picked up and dropped to compact soil
  - Introduction of steam power in the nineteenth century made possible the introduction of "modern" mechanised earth moving equipment
    - Panama Canal: Excavation of the Culebra Cut (1907) required the movement of 75,000,000 m^3 of earth

- Historic methods
  - Hydraulic fills
    - Popular technique between 1900 and 1940 for moving large amounts of earth
    - Involved mixing the soil with large quantities of water, conveying the mixture through pipes to the sites and depositing it at desired locations
    - No compaction was done, which insured unstable fills with high settlement potential
    - 3,800,000 m^3 landslide at the last large hydraulic fill job (Ft. Peck Dam, Montana, 1938) helped to end this practice
    - Higher capacity earthmoving equipment has made hydraulic fills unnecessary in any case

Earthmoving Equipment

- Key development: the tractor or crawler
  - Basic task: to convert engine power into traction
  - First tractors were developed in early 20th century for agricultural and military (tanks) applications
  - Mounting
    - All early tractors were track mounted
    - Modern track mounted equipment is powerful and mobile, but operates at slow speeds (< 11 kph or 7 mph)
    - Wheel mounted tractors are available for speeds up to 50 kph (30 mph), but has less traction and not as well suited for rough terrain

Earthmoving Equipment

- Tractors or Crawlers
  - Based on a "modular" concept, starting with a tractor base and adding attachments for various jobs
    - Bulldozer is most common; the movable steel blade can cut, move, spread, and mix soil along with other operations

Earthmoving Equipment

- Tractors or Crawlers
  - Loader can pick up, transport, and deposit soil
- Hoe type earthmoving equipment
  - Special tractors with a loader on one end and a hoe on the other are backhoes
  - Larger tractors without the loader are excavators

Earthmoving Equipment

- Tractors or Crawlers
  - Hoe type earthmoving equipment
    - Excavators and backhoes are versatile types of equipment that can be used for a wide variety of tasks
    - Shown is a vibratory pile driver mounted on an excavator; vibratory compactors can be mounted there also

Conventional Earthwork

- Definition of conventional earthwork
  - The excavation, transport, placement and compaction of soil or soft rock in areas where equipment can move freely
- Clearing and Grubbing
  - Involves removal of vegetation, trash, debris and other undesirable materials from areas to be cut or filled
  - Clearing is the above-ground portion of the work
  - Grubbing is the below-ground portion of the work
  - Mix of materials to be moved varies from site to site
- Stripping
  - Removing and storing the topsoil; topsoil is valuable for growing plants
- Oversize Items
  - Limited quantities of inorganic debris such as chunks of concrete, bricks or asphalt do not need to be hauled away if they are no larger than 250 mm (10")
  - Items larger than this are oversize and need to be hauled away
  - This is especially important with areas for pile foundations and in the upper 3 m of the soil

Conventional Earthwork

- Excavation
  - Most excavation takes place at the construction site
  - If insufficient material exists on site, material may be obtained from offsite borrow pits
  - Areas to be filled need to have the loose upper soils removed
  - Although loaders can be used with trucks to haul dirt, scrapers are more efficient, as they load, move, and unload dirt
  - If ground is too hard for scrapers or loads, it can be loosened using a ripper

- Excavation
  - When rippers do not work, it may become necessary to blast; this is especially important in rock
  - Chemicals that expand and break rocks apart can sometimes be used in lieu of blasting
  - Rippability or excavatability at a site can generally be evaluated from a visual inspection
    - At questionable sites, measurement of seismic wave velocity can help in selecting proper equipment
    - Soil and rock with seismic velocities of less than 500 m/sec (1600 ft/sec) can be excavated without ripping

Conventional Earthwork

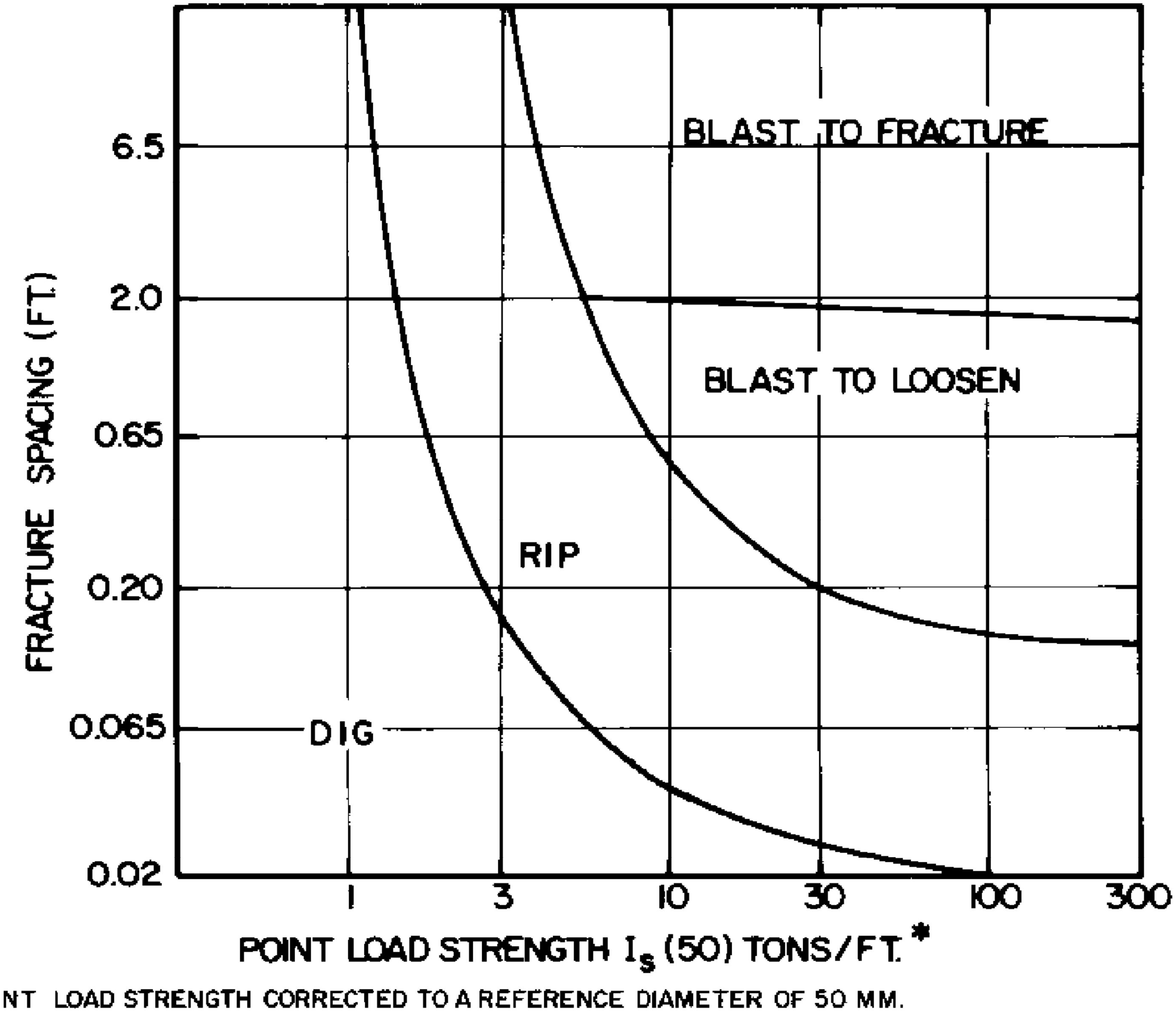


FIGURE 9
Suggested Guide for Ease of Excavation

Conventional Earthwork

Seismic Velocity

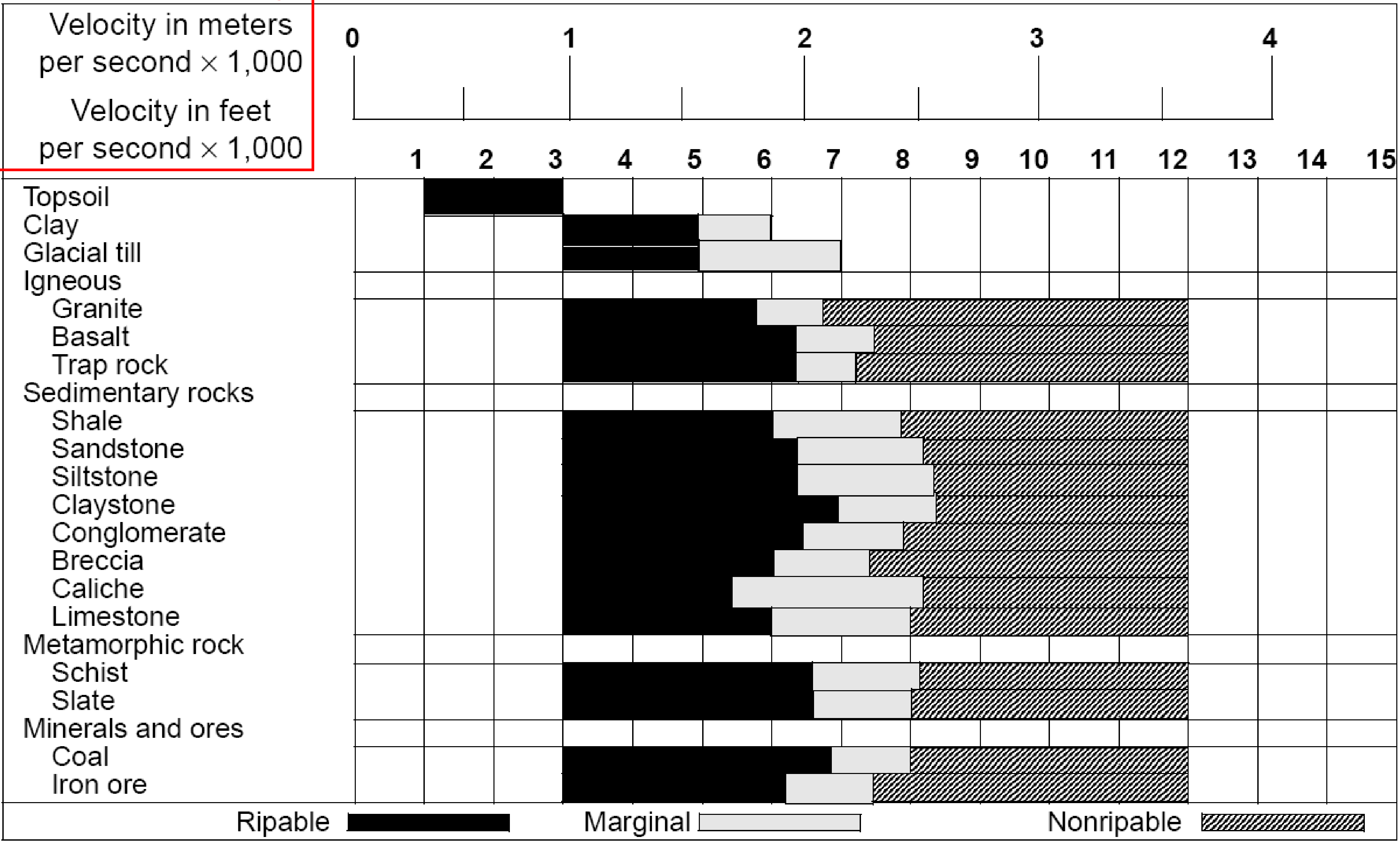


Figure 2-16. Ripping Performance for a 300-Horsepower Dozer With a Single- or Multishank Ripper

Conventional Earthwork

- The method of excavation can determine the way in which the job is paid for
  - Unclassified: contractor receives the same unit price for all materials
  - Classified: price depends on ease of excavation
    - Common: soil
    - Rock
    - To avoid problems, specifications for a classified excavation need to clearly define each category
- Transport and Placement
  - Scrapers can be used for moderate length hauls, but cannot be used to haul over public highways
  - Dump trucks can be used when the soil is loaded with loaders; they usually can move over public highways, and are faster than scrapers
  - For long distance hauling, wagons can be used; these are towed by semi tractors and are self-unloading when the site is reached
  - Conveyor belts are used on very large jobs and the soil is transported to a confined area

Conventional Earthwork

- Transport and Placement
  - Once soil arrives on site, it must be laid out in thin horizontal lifts, usually about 200 mm thick
  - Each lift must be moisture-conditioned and compacted before the next lift is placed
  - If compaction specifications require it, additional moisture needs to be added, usually by water trucks spraying each lift
  - Clay soils can be especially difficult to mix soil and water
- Compaction
  - Compaction equipment is used to compress the soil into a smaller volume, increasing the dry unit weight and improving its engineering properties
  - Soil compaction results in the reduction of the volume of the air in the soil
  - Early compaction equipment included animals, logs used as rammers, and rollers hauled by horses or steam tractors
  - Although construction equipment does some compaction while going over the site, it is generally not enough

Conventional Earthwork

- Compaction
  - Methods of compaction
    - Pressure: contact pressure between equipment and ground compacts soil; sheepsfoot roller has a contact of pressure of around 3500 kPa (500 psi)
    - Impact: blows to the soil give a very high pressure in a short period of time; repeated rapidly, this can induce compaction
    - Vibration: Vibratory compaction rearranges the soil particles, thus compacting them. Uses frequencies from 1000-3500 RPM
    - Manipulation: Shearing forces can also compact. Also called kneading. Can be detrimental with very wet fills.

Conventional Earthwork

- Sheepsfoot Roller
  - Developed by a Los Angeles contractor after a flock of sheep compacted a roadway
  - As rolled, projecting feet by a combination of tamping and kneading
  - Pressures vary from 100 – 600 psi (700 – 4200 kPa)
  - Larger units will compact layers on the order of 300 mm (12") in 3-5 passes
  - Most suitable for fine grained soils (clays and silts)

Conventional Earthwork

- Pneumatic Tire Rollers
  - Compact primarily by kneading
  - Usually outfitted with a weight box for additional compression
  - Small equipment will compact 150 mm (6") layers
  - Large equipment will compact 300 mm (12") layers
  - Useful in a wide variety of soils

Conventional Earthwork

- Vibratory Compactors
  - Compact soils by densify soils through shaking
  - Attempt to find the resonant frequency of soils with units that can vary the frequency
  - Can be mounted on smooth drum, sheepsfoot, and pneumatic tire units
  - The finer the material, the thickness of the layer to be compacted can be reduced
  - Best used in granular soils but applicable to all soil types

Conventional Earthwork

- Smooth Drum Rollers
  - Misnamed "steamrollers"; no longer powered by steam
  - Not well suited for compacting fill
  - Can be utilised for compacting limited thicknesses of material, such as highway and airfield work
  - Provides a smooth surface so that rain will run off of the worksite

Impact Roller

- A conventional tractor pulls a heavy prism-shaped mass, consisting of steel or concrete.
- The impact generated by the rotation of the heavy mass (up to 50 tons) transfers sufficient energy to achieve medium compaction to a depth of several meters.

Conventional Earthwork

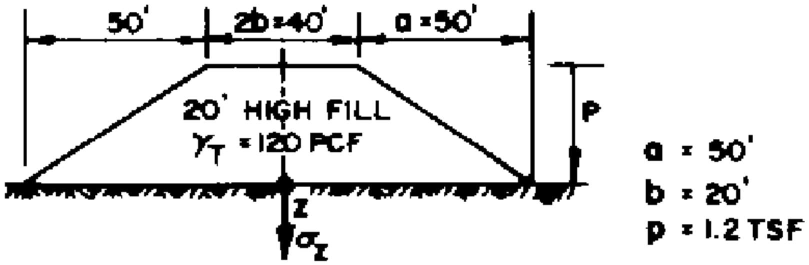
- Fine Grading
  - Once all lifts are in place, rough grading is done
  - Fine grading consists of carefully trimming and filling to produce the desired configuration
  - Motor grader or blade is often used for this purpose

Soil Improvement other than Compaction

- Removal and replacement
- Precompression
- In-situ densification
- In-situ replacement
- Grouting
- Stabilisation using admixtures
- Reinforcement

Removal and Replacement

- One of the oldest and simplest methods of soil improvement is simply to remove and replace the soil
- A very viable option is soil has problems that conventional compaction cannot deal with, such as contaminated soils or organic soils; finding a place to haul such soils to may be difficult
- Method is usually practical only above the groundwater table; earthwork operations below are very difficult, even if the site has been dewatered

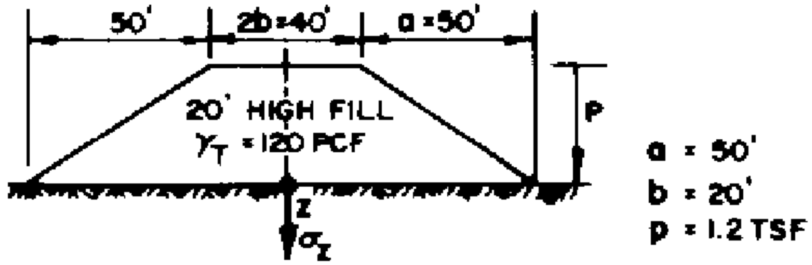


DETERMINE PROFILE OF APPLIED STRESS σ_z BENEATH ℄ OF EMBANKMENT OF INFINITE LENGTH.

Precompression

- Simply places a surcharge fill (temporary, permanent, or a combination of both) on top of the soil that requires consolidation (silty and clayey soils)
- Once sufficient consolidation has taken place, the fill can be removed and construction take place
- Surcharge fills are typically 3-8 m (10-25') thick, and generally produce settlements of 300 – 1000 mm (1 – 3 ft.)
- Most effective in clay soils; sands are better vibrated for improvement

- Advantages of Precompression
  - Requires only conventional earthmoving equipment, readily available; no special or proprietary equipment is needed
  - Any grading contractor can perform the work
  - Results can be effectively monitored by using appropriate instrumentation (especially piezometers) and ground level surveys
  - Long track record of success
  - Cost is comparatively low



DETERMINE PROFILE OF APPLIED STRESS σ_z BENEATH ℄ OF EMBANKMENT OF INFINITE LENGTH.

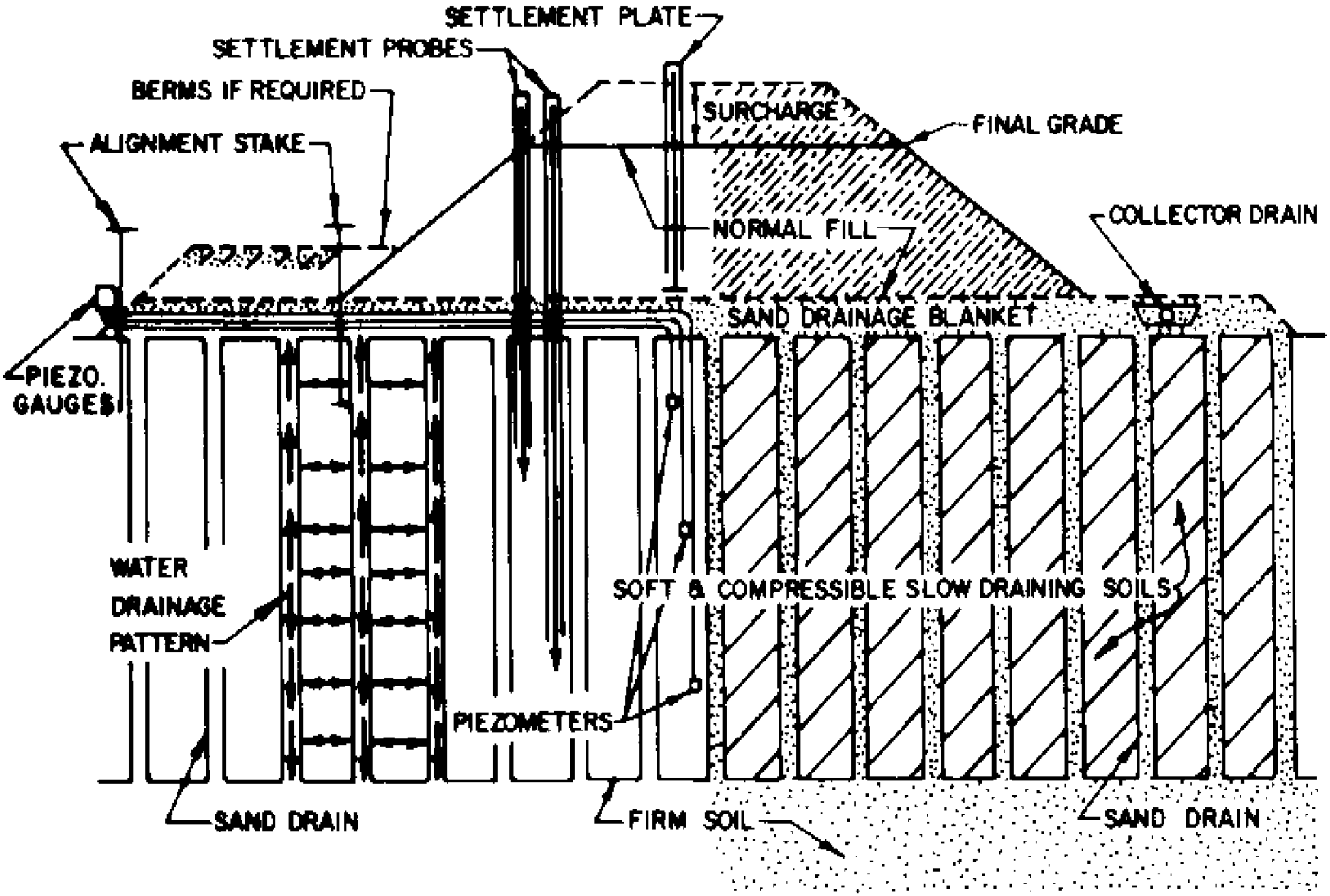
Precompression

- Disadvantages of Precompression
  - Surcharge fill must extend horizontally at least 10 m (33') beyond the perimeter of the planned construction, which may not be possible at confined sites
  - Transport of large quantities of soil on and off the site may not be practical, or may have unacceptable environmental (noise, traffic, dust) impacts on adjacent areas
  - Surcharge must remain in place for months or years, thus delaying construction

Vertical Drains

- Vertical drains are installed under a surcharge load to accelerate the drainage of impervious soils and thus speed the consolidation of these soils
- These drains provide a shorter path for the water to flow through to get away from the soil
- Time to drain saturated clay layers can be reduced from years to only a couple of months
- Vertical drains can be used with a permanent fill, thus eliminating the need to remove a surcharge fill

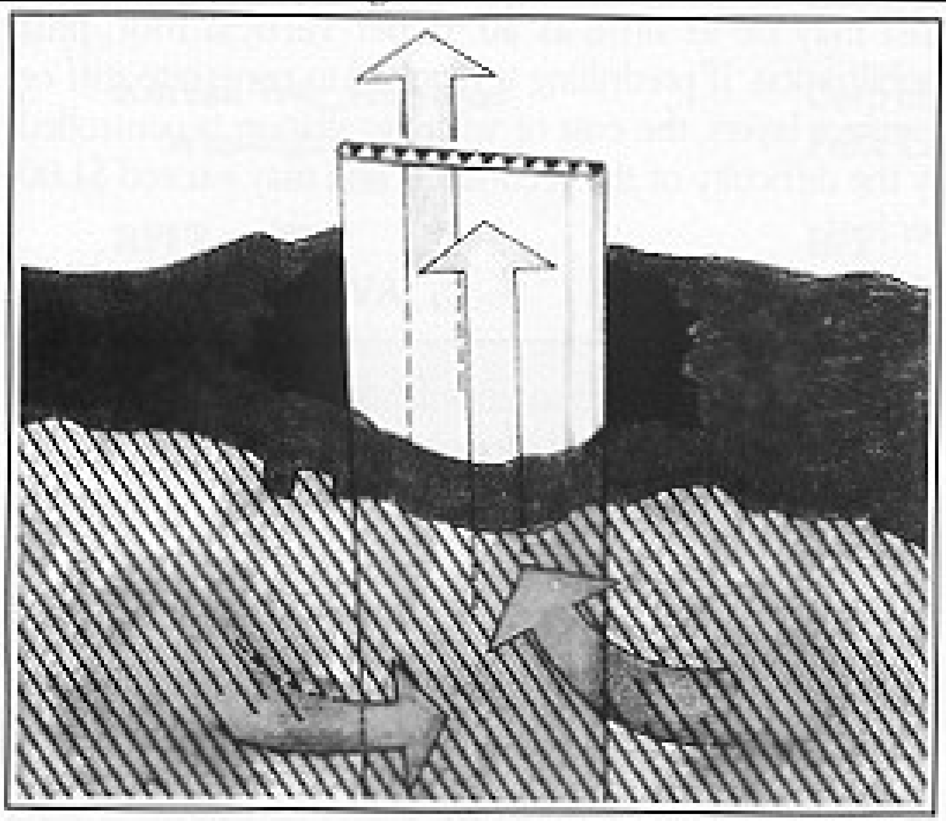
Vertical Drains



TYPICAL SAND DRAIN INSTALLATION

Wick Drains

- Geosynthetic used as a substitute to sand columns; arrayed in a similar manner to the sand drains
- Installed by being pushed or vibrated into the ground (normally spooled)
- Most are about 100 mm wide and 5 mm thick



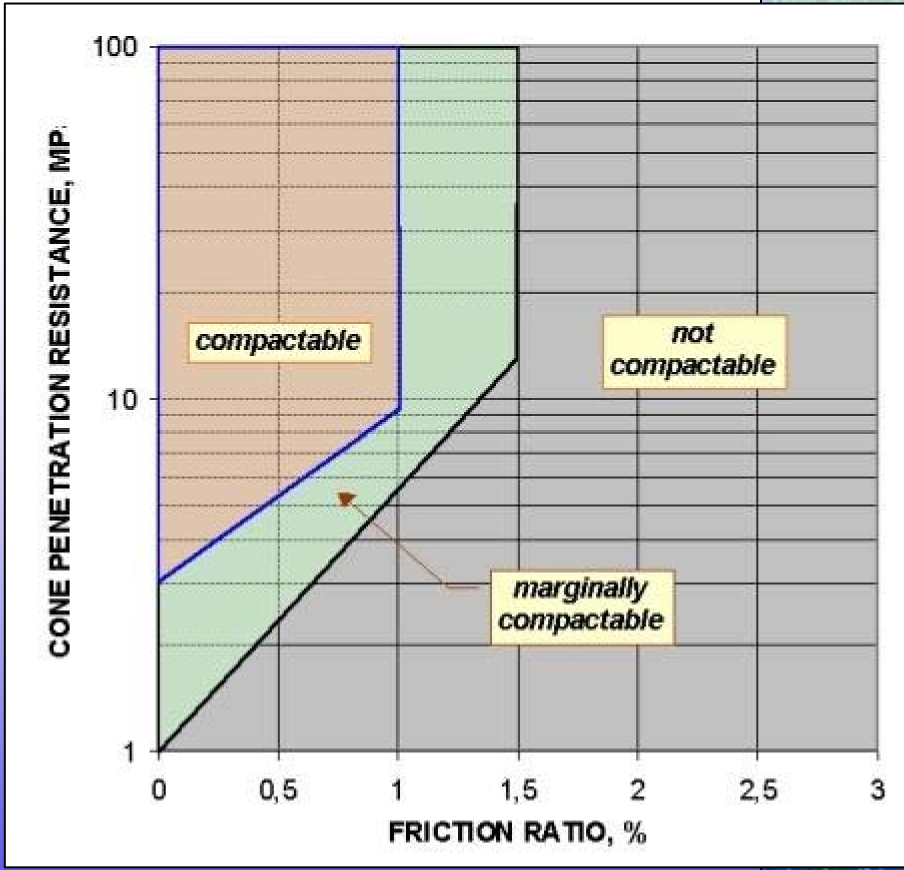
Pore water flows laterally to the wick drains and is carried vertically up to the ground surface.

Installation of Wick Drains

- Typically spaced on 3 m centres
- Most effective in clay soils
- Wicks usually "pushed" with a mandrel, but sometimes must be vibrated

In-situ densification

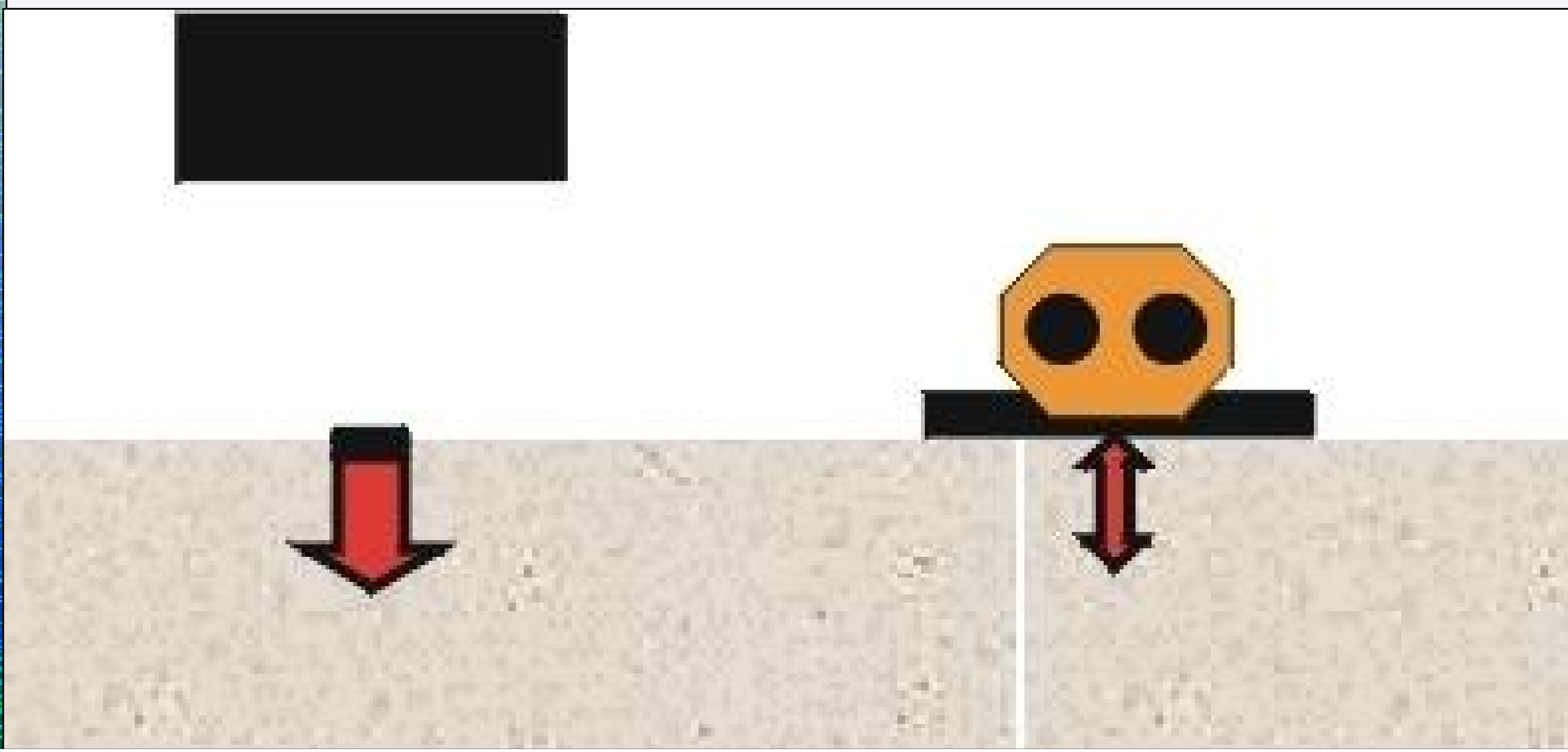
- Most effective in sands
- Methods used in conventional earthwork (sheepsfoot roller, etc.) are only effective to about 2 m below the surface
- In-situ densification methods described here are designed for soils deeper than can be compacted from the surface



Dynamic vs. Vibratory Methods

Dynamic (Impact)

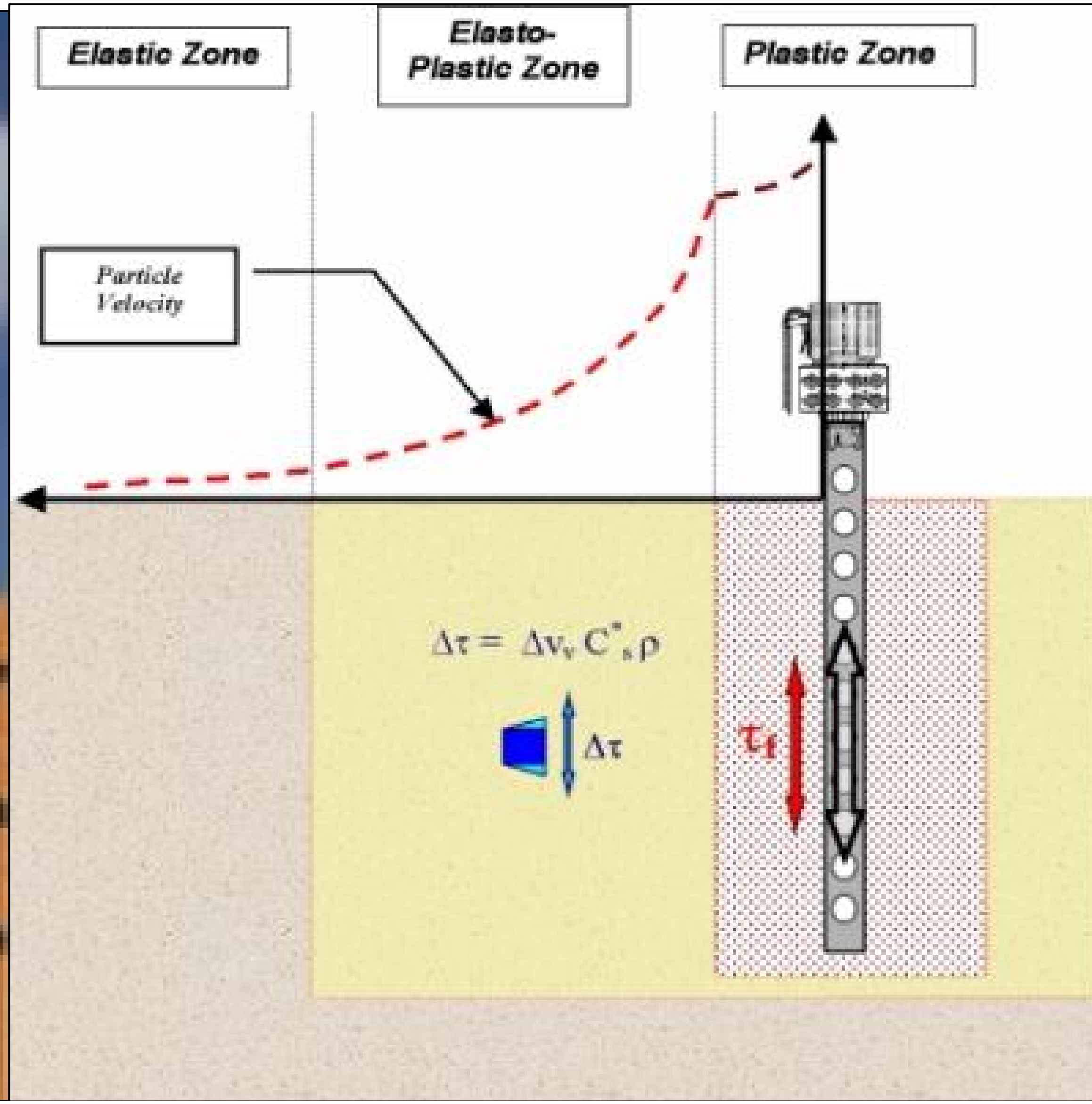
Vibratory



Vibratory Probe Compaction

- Long probe mounted onto a vibratory pile driver compacts the soil around the probe; penetrations spaced in a grid pattern similar to vertical drains
  - Examples of Vibratory Probe Compaction
    - Terraprobe: uses pipe for the probe; never popular and now obsolete
    - Tri-star: uses a Y-shaped probe with small horizontal ribs on the main plates; probes up to 25 m long; more efficient than pipe
    - Resonance Compaction: uses an H-beam with a perforated web along with extensive instrumentation of machine and soil to find the resonance of the soil and thus vibrate the soil at the optimum frequency and amplitude

Resonance Compaction



Vibroflotation

- Special type of vibratory probe
  - Mounts the rotating eccentric weight in a round probe which then penetrates the soil
  - Probe includes both the vibrator mechanism and water jets
  - Probe is lowered into the ground using a crane
  - Vibratory eccentric force induces compaction and water jets assist in insertion and extraction
- Vibratory probe compaction is effective if silt content < 12-15% and clay < 3%
- Probes inserted in grid pattern with 1.5 – 4 m spacings

Vibroflotation

Dynamic Compaction

- Uses a special crane to lift 4-27 Mg (5-30 tons) weight (pounder) to heights of 12-30 m (40-100') then drop these weights onto the ground
- Although crude, it can be a cost-effective method of densifying loose sandy and silty soils up to 5-10 m (15-30') deep

In-situ replacement

- Replacement of compressible or weak soil with soil of higher strength without excavation
- A vibroflot can create a shaft that is backfilled with gravel to form a stone column
- Alternatively, dynamic compaction equipment can pound gravel in to the ground for the same effect
- Stone columns also act as vertical drains, accelerating consolidation

Grouting

- Definition
  - The injection of a special liquid or slurry materials called grout into the ground for the purpose of improving the soil or rock
- Types of Grouts
  - Cementitious grouts are made of Portland cement that hydrates after injected, forming a solid mass
  - Chemical grouts include a wide variety of chemicals that solidify once they are injected into the ground
  - Chemical grouts are more versatile, but also more expensive and in some cases toxic

Grouting Methods

- Intrusion Grouting
  - Consists of filling joints or fractures in rock or soil by injecting grout through pipes
  - Primary benefit is decrease in hydraulic conductivity
  - Used to prepare foundations and abutments for dams
  - Usually done using cementatious grouts
- Permeation Grouting
  - Injected of thin grouts in to the soil so that they penetrate into the voids
  - Once the soil cures, it becomes a nearly solid mass

Grouting Methods

- Permeation Grouting
  - Most permeation grouting is done using chemical grouts, as these can be thinner than cementatious grouts and thus enter the voids more easily
  - Often used to form groundwater barriers and to stabilise soils in advance of making excavations or tunnels
- Compaction Grouting
  - Uses a stiff (25 mm slump) grout that is injected into the ground under high pressure through a pipe to form a series of inclusions

Grouting Methods

- Compaction Grouting
  - Grout is too thick to penetrate the soil, but grout inclusions compact the adjacent soil
  - Often used to repair structures that have experienced excessive settlement
- Jet Grouting
  - Developed in Japan; uses a special pipe equipped with horizontal jets that inject grout into the soil at high pressure
  - Pipes are first inserted, then raised and rotated to form a column of treated soil
  - Method is usable on wide variety of soils and has been used on a wide variety of applications

Stabilisation using admixtures

- Most common admixtures is Portland cement
- When mixed with soil, it forms a material called soil-cement, which is comparable to a weak concrete
- Other admixture materials include lime and asphalt
- Objective is to provide artificial cementation, thus increasing strength and reducing both compressiblity and hydraulic conductivity
- Used to reduce expansion potential of clays

Surface Mixing

- The type of soil mixing that historically has been the most common
- Performed by ripping the upper soils, applying the admixture, mixing with special equipment, and compacting
- Mixture upon curing forms a hard and durable soil
- Used frequently in forming subbases for highways and airports
- Layer usually no more than 200 mm (8") thick
- When properly designed and constructed, they can be cost efficient
- Construction process is very time-sensitive, as the mixture must be shaped to grade and compacted before curing goes too far
- Usually requires specialised equipment to achieve thorough mixing
- Poor mixing results in hard and soft spots, which may actually have a worse result than the original condition

In-Situ Dense Mixing

- Uses rotating mixer shafts, paddles or jets that penetrate into the ground while injecting and mixing Portland cement or other stabilising agent
- Result is soil with lower compressibility and hydraulic conductivity
- Types of in-situ dense mixing
  - Deep jet cement mixing
  - Soil mix walls
  - Deep jet mixing
  - Deep soil mixing
  - Deep mixed method

Reinforcement

- Soil, like concrete, is stronger in compression than in tension
- Use of a plastic grid, steel strips or geotextiles, like reinforcing concrete, can improve the soil stability and increase its load carrying capacity
- Plastic grids are the most common tensile reinforcement material because of their durability and low cost
- Especially useful in the construction of compacted fill slopes and earth-retaining structures

Material for Mid-Term Exam

- Open Book
  - You should organise your print-outs of the lecture slides for easy reference
  - Don’t forget the printouts you need from the FHWA and NAVFAC Documents
- Material
  - Most material covered in Homework Sets 1 & 2
    - Introduction: Foundations in Civil Engineering; Performance Requirements
    - Shallow Foundations: General
    - Shallow Foundations: Bearing Capacity
    - Spread Footings: Geotechnical Design (incl. settlement)
    - Spread Footings: Structural Design
    - Mat Foundations

Questions?