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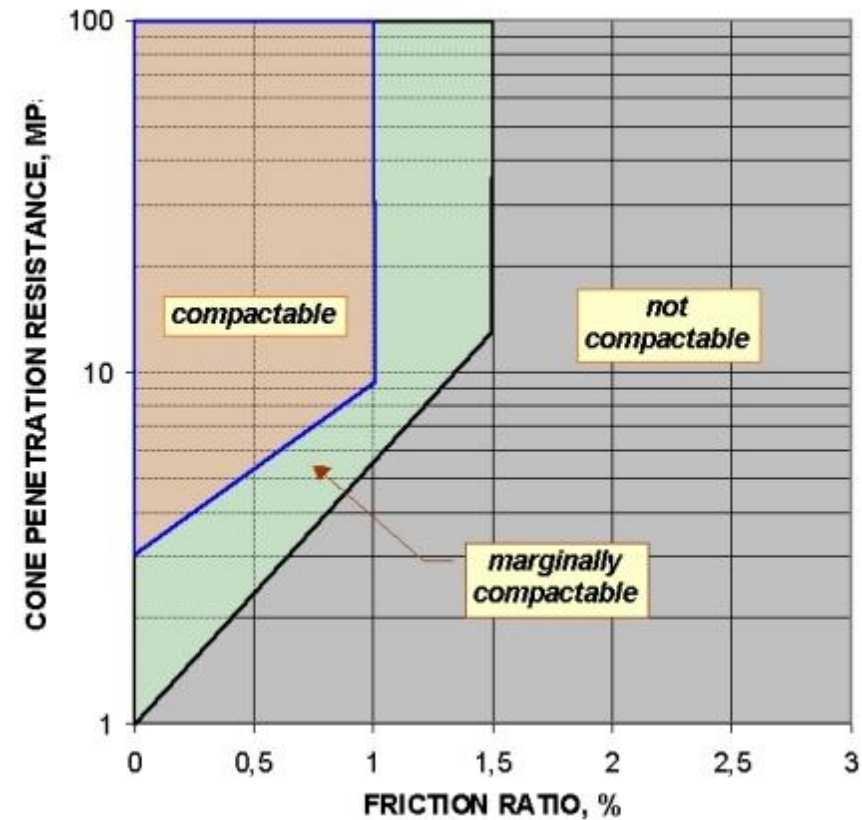
Foundation Analysis and Design



Soil Improvement (Part II)

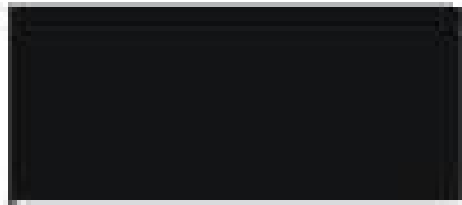
In-situ densification

- 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

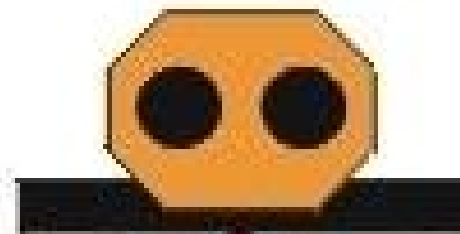


Dynamic vs. Vibratory Methods

Dynamic (Impact)



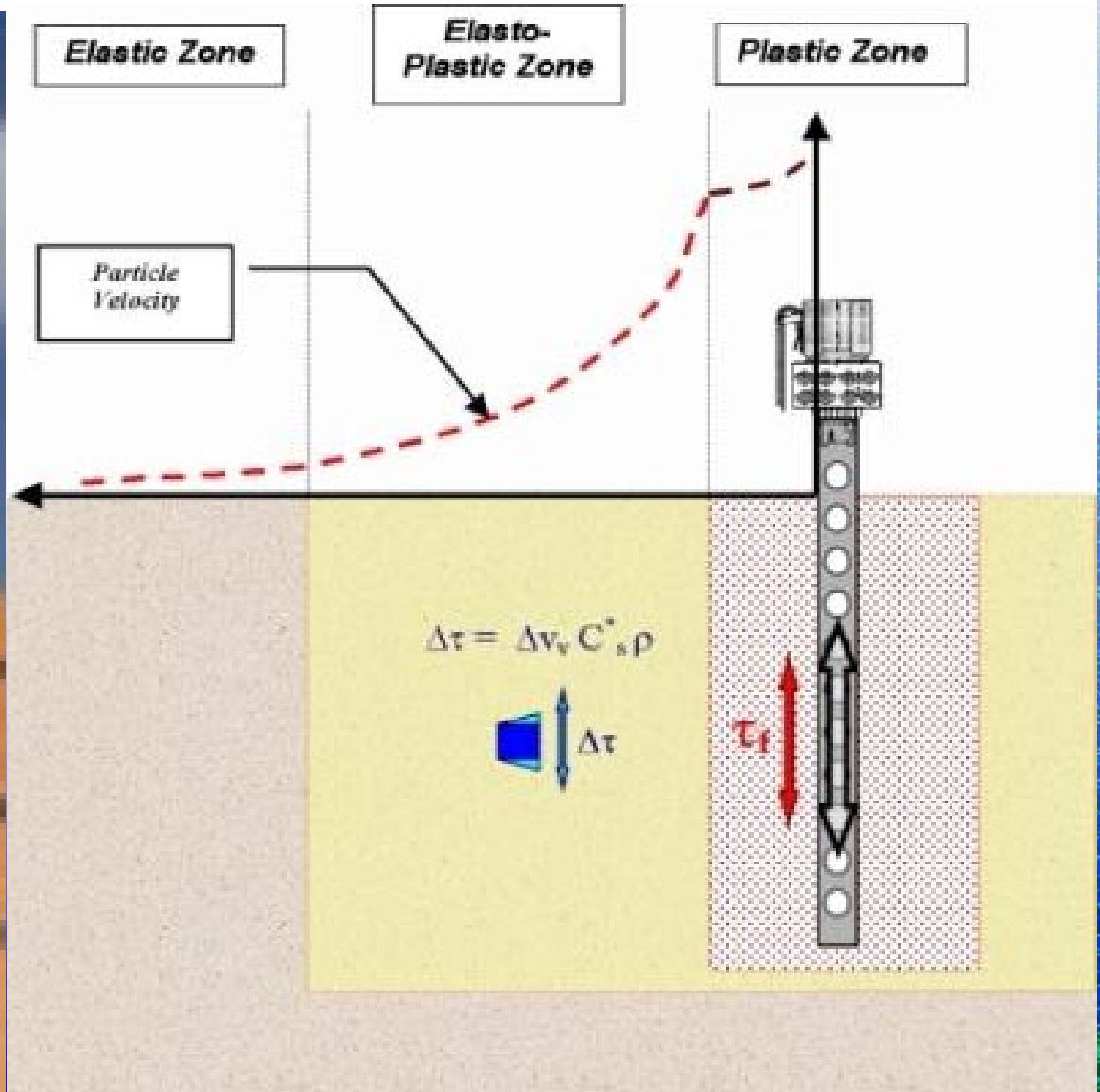
Vibratory



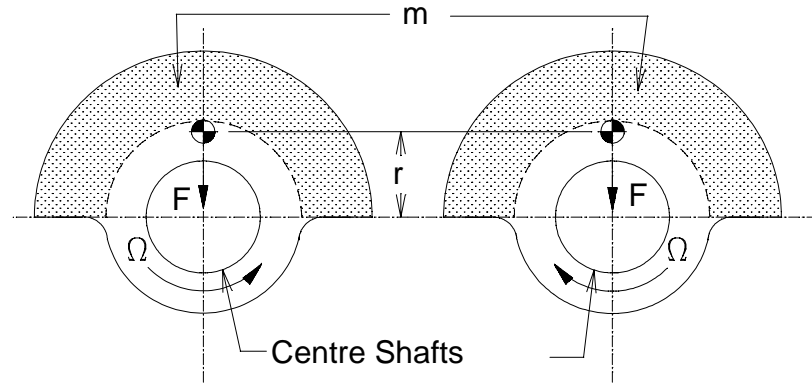
Vibratory Probe Compaction

- 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

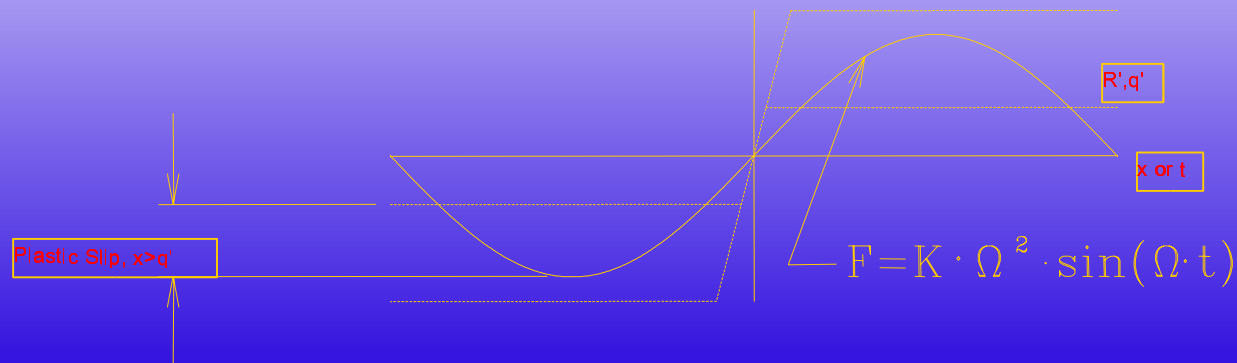
Resonance Compaction



Operating Principle



- Vibratory hammers apply a rapidly alternating force to the pile by rotating eccentric weights about horizontal shafts
- Each eccentric produces centrifugal, dynamic force acting in a single plane and directed toward the centerline of the shaft
- The eccentrics are paired so the horizontal forces cancel each other, leaving only vertical force for the pile



Original Development

- First job in the USSR -- Gorki hydroelectric development, 1949

Model BT-5

Dynamic Force, 214 kN

Eccentric Frequency, 41.67 Hz

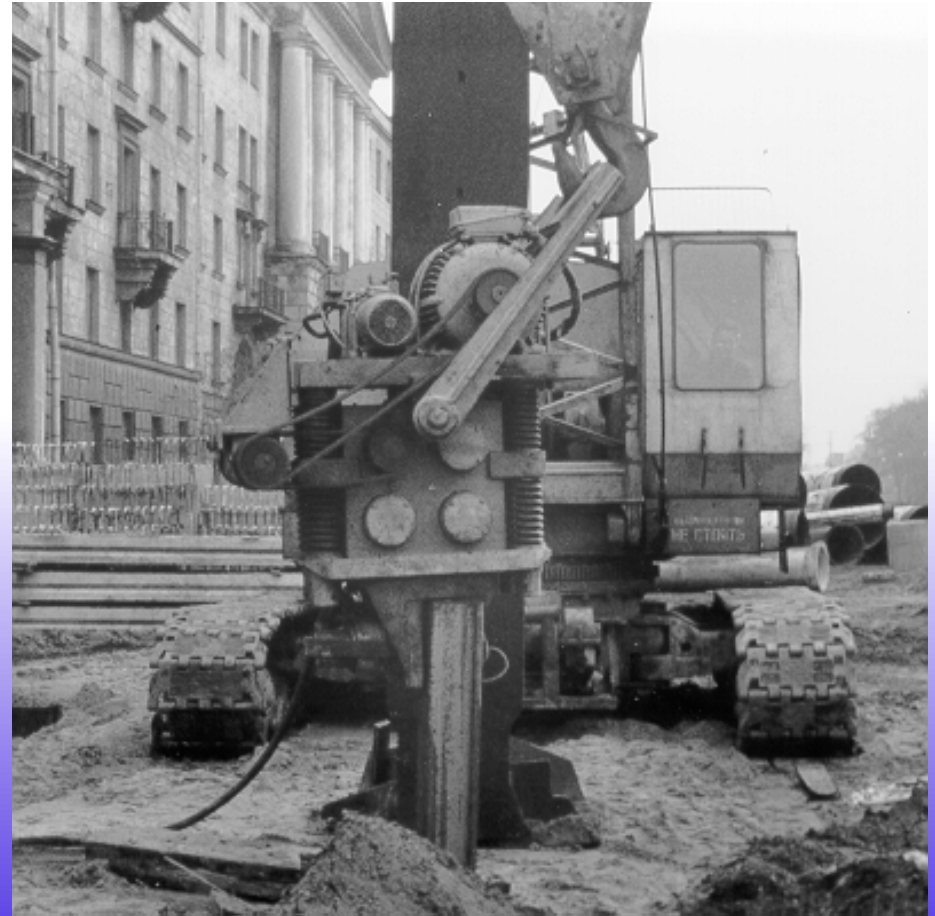
Power, 28 kW

- Sheet Piles

- » 3700 sheet piles
- » 9-12 m long
- » 2-3 minutes driving time

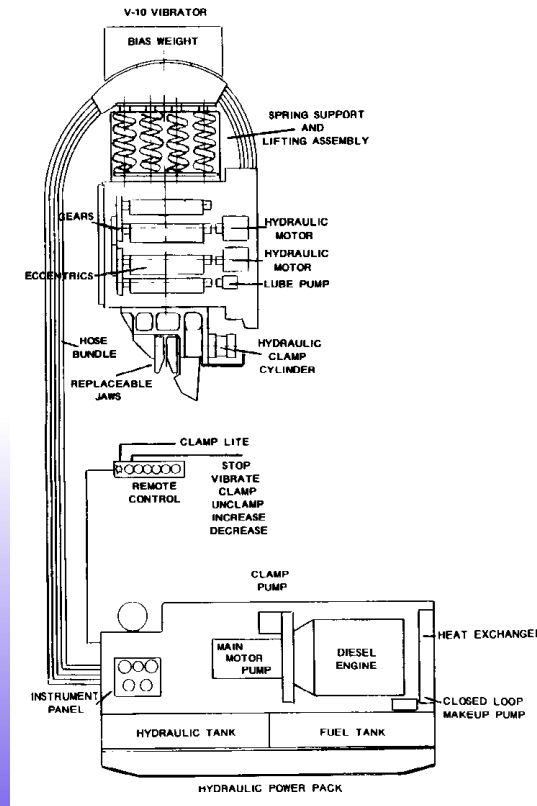
Soviet Equipment

- Soviet B-402 pile driver
 - Dynamic force, 270 kN
 - Maximum eccentric moment, 12 kg-m
 - Rotation frequency, 23.8 Hz
- Driving sheet piling in Leningrad (St. Petersburg)



Other Vibratories

- Japan
 - Nippei
 - Uraga
 - Tomen
- France
 - PTC
- Germany
 - Müller
 - MGF



- U.S.
 - MKT – first U.S. Vibratory (V-10)
 - Foster (PTC, then Nippei derived)
 - ICE (US and Europe)
 - Vulcan
 - HPSI
 - Ape

Basic Types of Vibratory Hammers

- Low frequency vibrators
- Medium frequency vibrators
- High frequency vibrators
 - Non-resonant
 - Resonant



Low Frequency Vibrators

- Characteristics

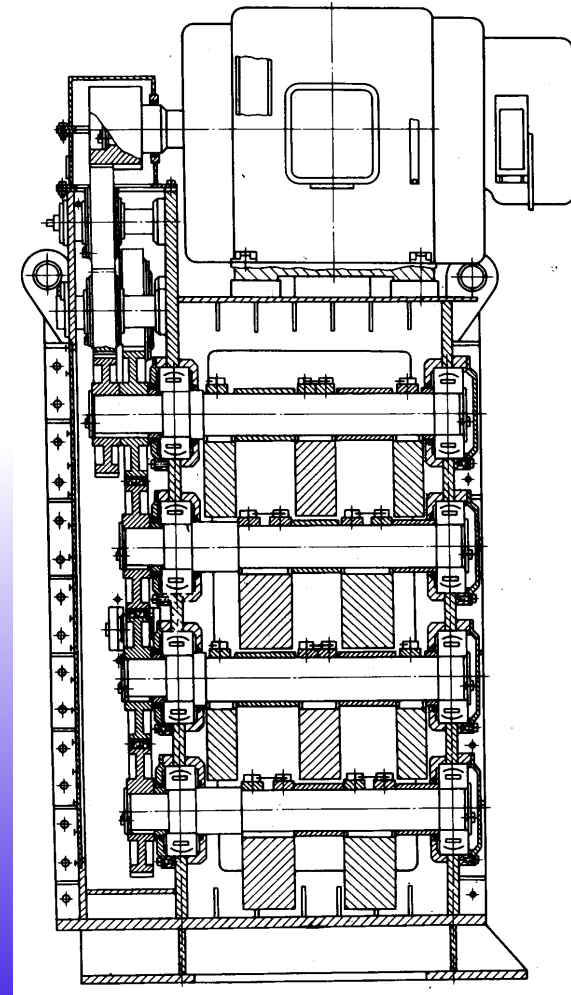
Vibration frequency of 5-10 Hz

Used with piles with high mass and toe resistance

Drive with high eccentric moments and amplitudes

- VPM-170

- Dynamic force 1,700 kN
- Frequency 9.17 hZ
- Eccentric moment 510 kg-m



Medium Frequency Vibrators

- Characteristics
 - Frequency range – 10-30 Hz
 - Balance of frequency, eccentric moment and dynamic force needed to drive wide variety of piles
 - Most larger vibratories fall in this range

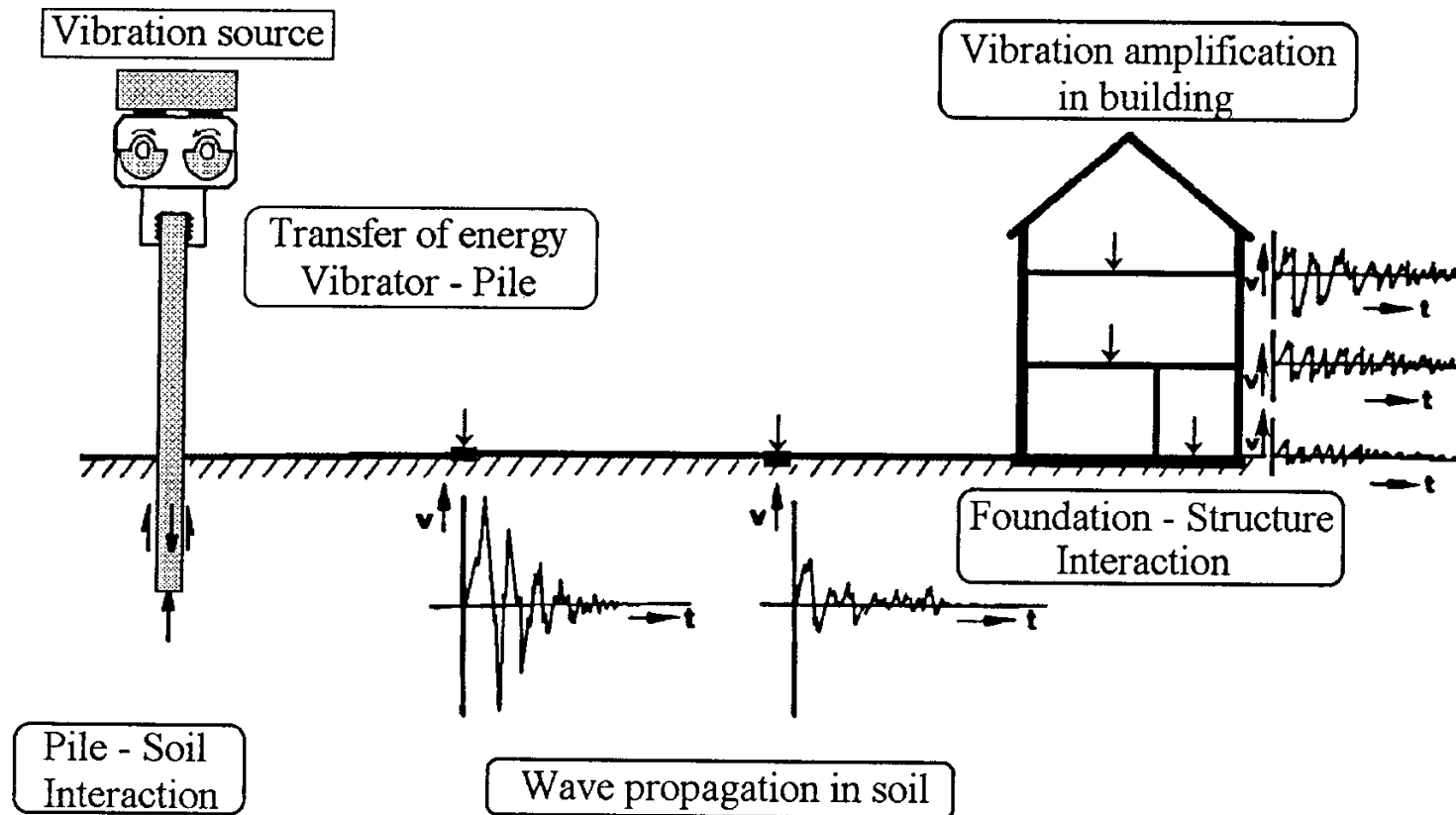


High Frequency Vibrators

- Characteristics
 - Operate at frequencies above 30 Hz
 - Reduces amplitude and velocity for decreased ground vibrations
- Two ranges
 - Non-resonant (Tramac)
 - Resonant



Transmission of Ground Vibrations



Resonant Vibrator

- Guild-Bodine vibrator
 - Operated at frequencies up to 120 Hz
 - Send “sound” waves into the pile to induce resonance
 - Mechanically complex and expensive



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 cementitious 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 cementitious 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

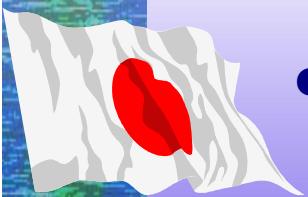
Grouting Methods

- **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 compressibility 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

Surface Mixing

- 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

Questions



Quiz 2



Quiz 2

- Relating to the placement of compacted earth fill (structural earth fill), indicate one suitable type of surface zone compaction equipment (such as sheepsfoot roller, vibratory roller, etc.) to use for easiest for more effective compaction of each of the following soil materials:
 - a) Well graded fine to coarse sand
 - b) Silty fine to coarse sand, trace clay
 - c) Silt of low plasticity, trace clay, and sand
 - d) Silty clay of low plasticity
 - e) Sand-silt-clay mixture, some gravel