MODULE 5

COMPACTION

- The most commonly used **ground improvement** technique, where the soil is **densified through external compactive effort/mechanical** means by **reducing volume of air.**
- It causes reduction in the volume of voids filled with air, while the volume of water and solids remains the same

The objectives of compaction are:

- To increase soil shear strength and therefore its bearing capacity.
- To reduce subsequent settlement under working loads.
- To reduce soil permeability and compressibility.

DENSIFICATION

- ***The compaction causes densification by***
- -reorientation of soil particle
- -fracture of of grains bond between them followed by reorientation of particle
- -distortion
- **Cohesive soil-** densification attained by distortion and reorientation which is resisted by inter particle forces
- **Cohesion less soil/ coarse grained soil-** by reorientation which is resisted by friction between the particle
- **Moisture content**

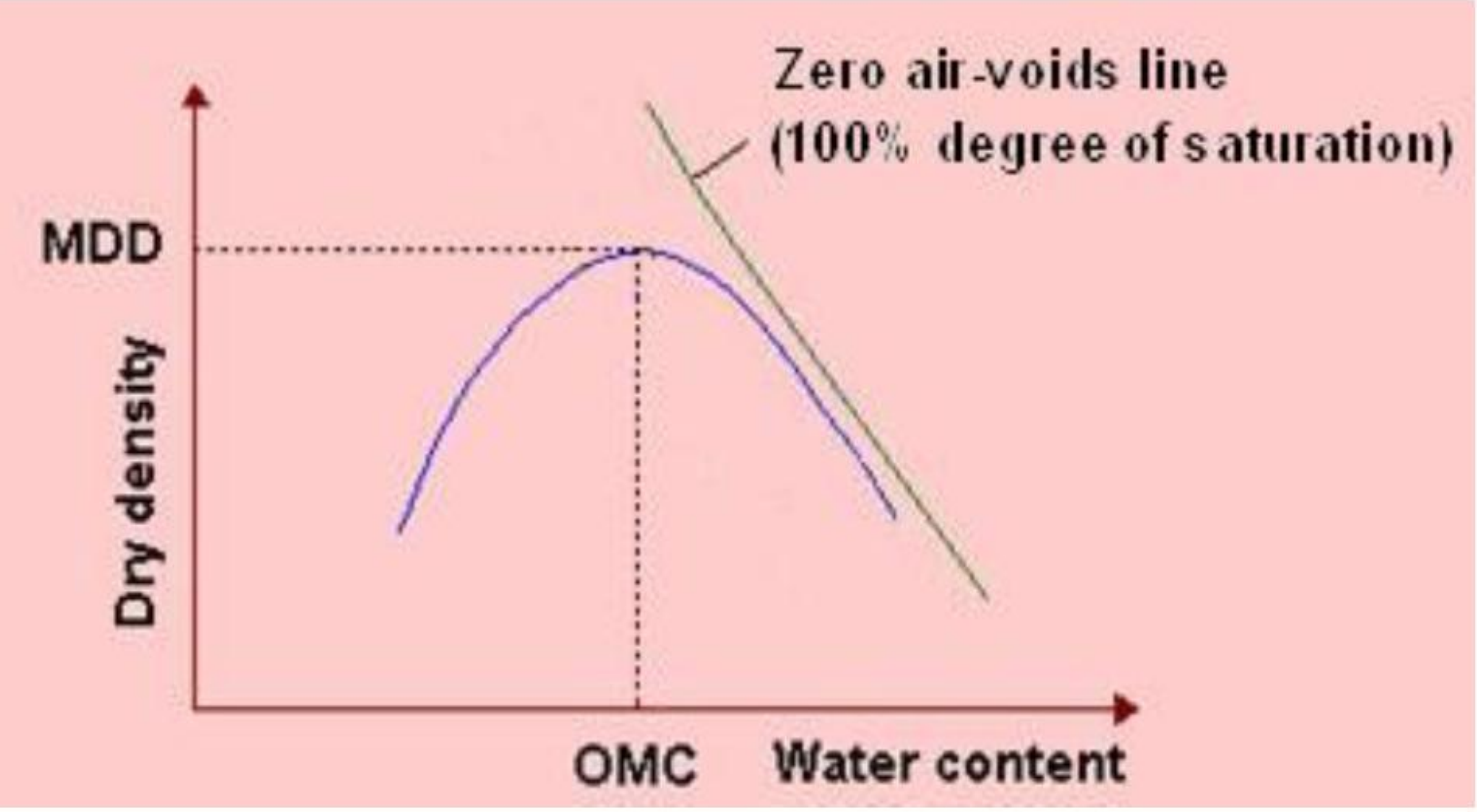
MOISTURE DENSITY RELATIONSHIP

- As water is added to a soil at low moisture contents, it becomes easier for the particles to move fast one another during the application of compacting force.
- The particles come closer, the voids are reduced and this causes the dry density to increase. As the water content increases, the soil particles develop larger water films around them.
- This increase in dry density continues till a stage is reached where water starts occupying the space that could have been occupied by the soil grains.
- Thus the water at this stage hinders the closer packing of grains and reduces the dry unit weight.
- The **maximum dry density (MDD)** occurs at an **optimum water content (OMC),** and their values can be obtained from the plot

Zero air void line

- – 100% saturation line
- Theoriticaly maximum dry density occurs when there is no air voids
- The relation between moisture content and dry unit weight for a saturated soil is the **zero air–voids line**.
- It is not feasible to expel **air** completely by compaction, no matter how much compactive effort is used and in whatever manner.

MOISTURE DENSITY RELATIONSHIP

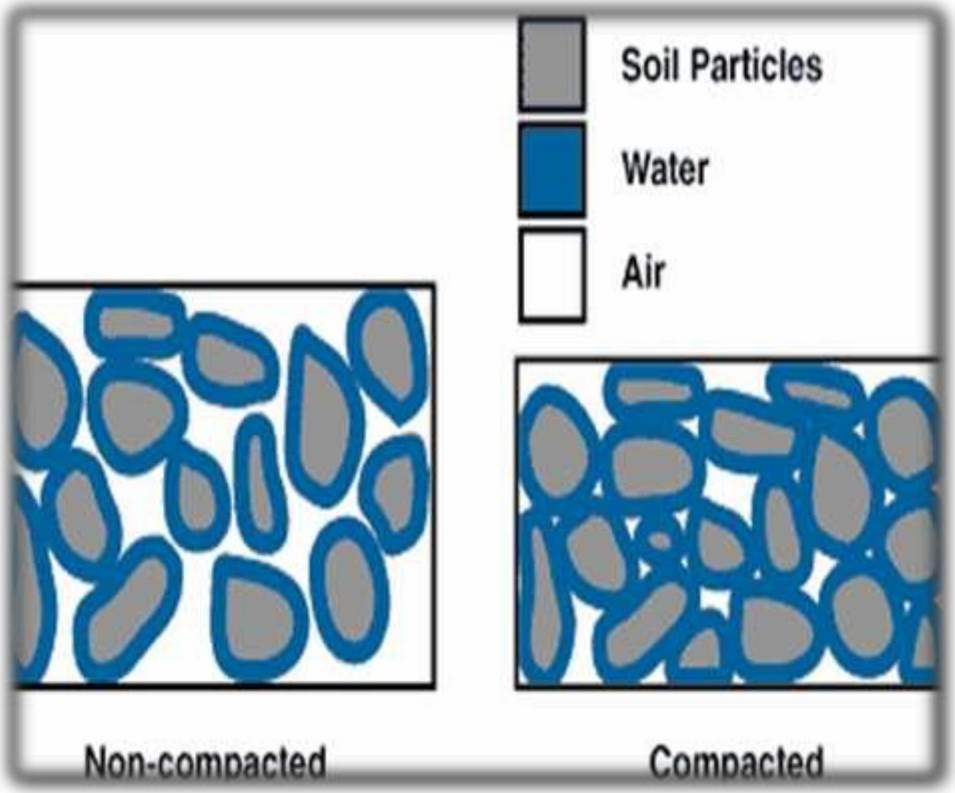


PROPERTIES OF COMPACTED SOIL

1) *Soil structure*
2) *Permeability*
3) *Swelling*
4) *Pore Water Pressure*
5) *shrinkage*
6) Compressibility
7) Stress-Strain Relationship
8) Shear Strength
   a) *Shear strength at moulded water content*
   b) *Shear strength after saturation*

EFFECT ON SOIL STRUCTURE

- *The water content at which the soil is compacted plays an important role in soil structure.*
- *Soils compacted at water content less than optimum water content have flocculated structure.*
- *Soils compacted at water content more than optimum water content have dispersed structure.*



EFFECT ON SOIL STRUCTURE

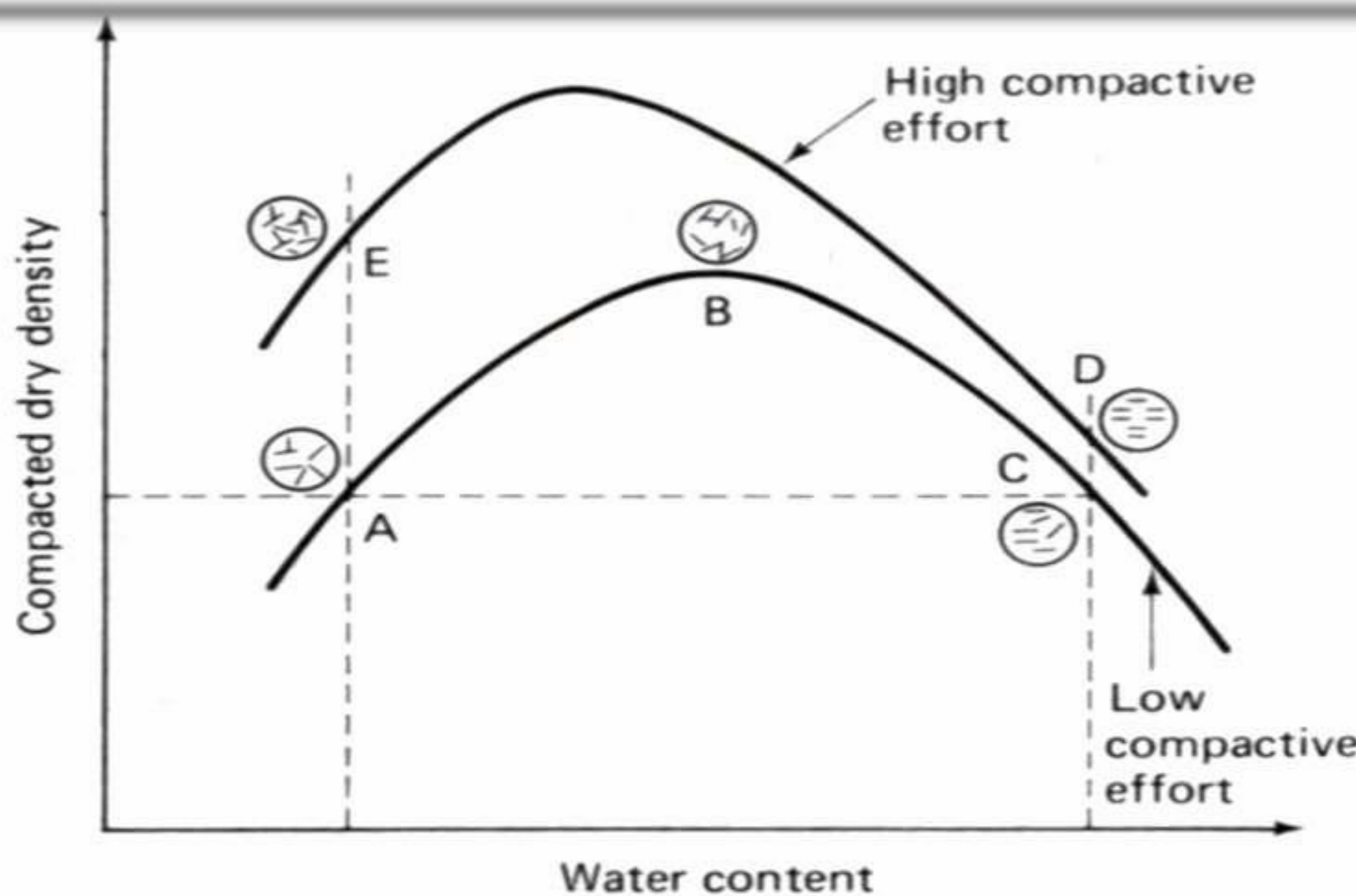


Fig. 5.5 Effect of compaction on soil structure (after Lambe, 1958a).

EFFECT ON SOIL STRUCTURE

- *At Point A, the water content is low and attractive forces are predominant, so results in flocculated structure.*
- *As the water content is increased beyond optimum, the repulsive forces increase and particles get oriented into a dispersed structure.*

EFFECT ON PERMEABILITY

- *Permeability of soil depends on void size.*
- *As water content increases, there is an improved orientation of particles resulting in reduction of void size and permeability.*
- *Above optimum water content ,the permeability slightly increases.*
- *If compactive effort is increased, the permeability decreases due to increased dry density.*

EFFECT ON SWELLING

- A soil compacted dry of the optimum has low water content and more random orientation of soil particle
- It imbibes more water than the sample compacted wet of the optimum, and has therefore more swelling

EFFECT ON PORE WATER PRESSURE

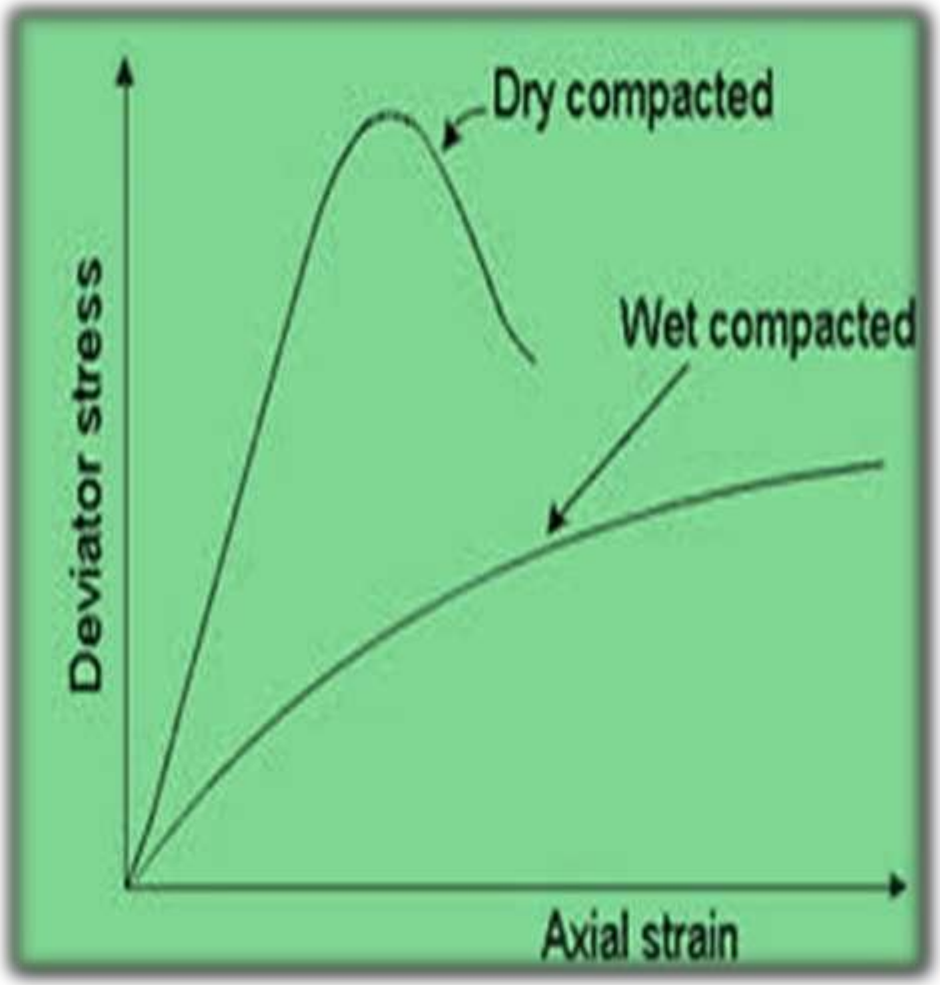
- *It is defined as pressure of ground water held within a rock or soil, in gaps between particles (pores).*
- *The pore water pressure for soil compacted dry of optimum is therefore less than that for the same soil compacted wet of optimum.*

EFFECT ON SHRINKAGE

- *Soils compacted dry of optimum shrink less when compared to compacted wet of optimum.*
- *The soils compacted wet of optimum shrink more because the soil particles in dispersed structure can pack more efficiently.*

EFFECT ON STRAIN-STRESS RELATIONSHIP

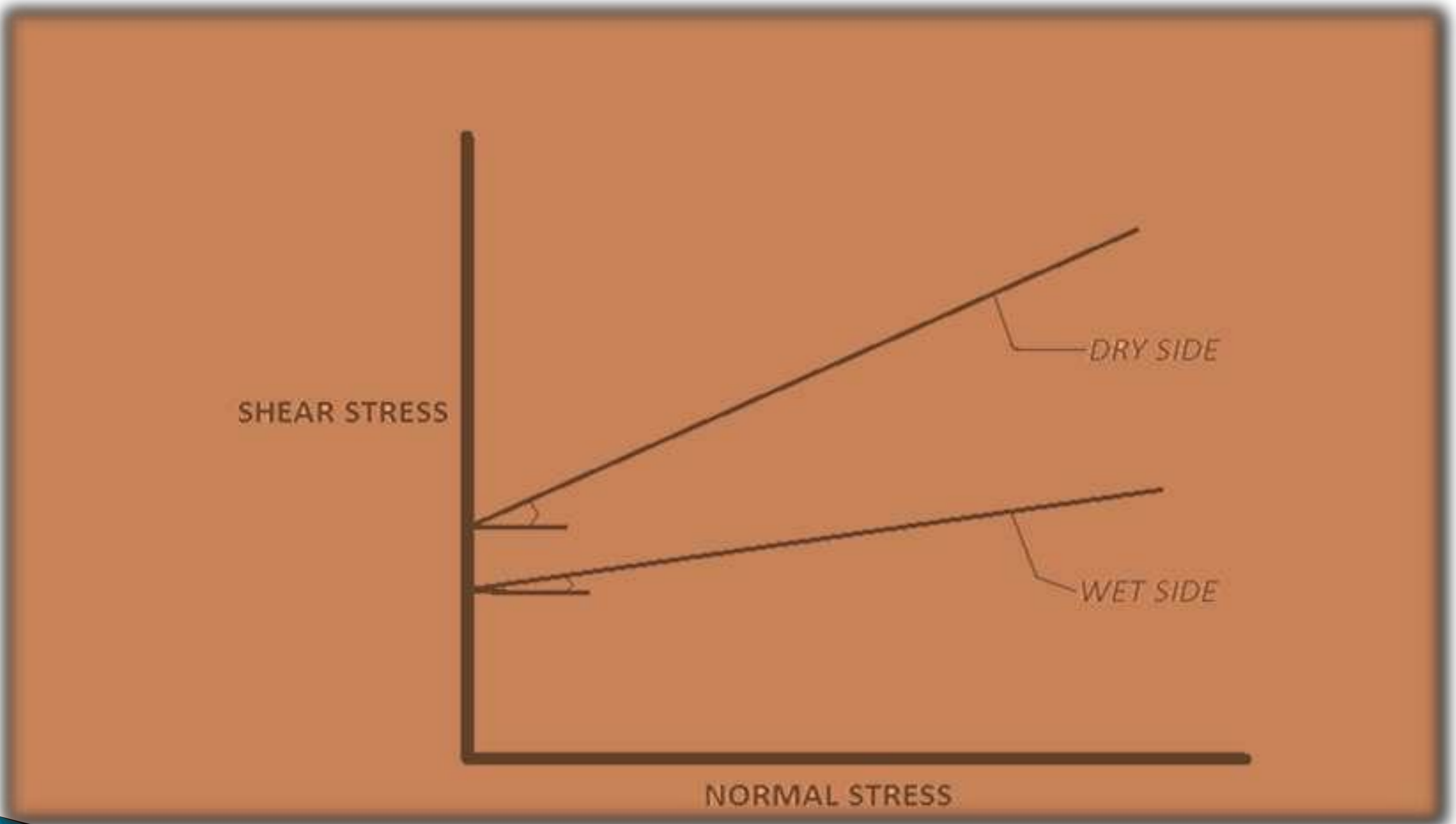
- *The soil compacted dry of optimum have steeper stress-strain curve than those on wet side.*
- *The strength and modulus of elasticity of soil on dry side of optimum will be high.*
- *Soil compacted dry of optimum shows brittle failure.*
- *And soils compacted on wet side experience increased strain*



EFFECT ON SHEAR STRENGTH

- *In general, the soils compacted dryof optimum have a higher shear strength than wet of optimum at lower strains.*
- *However at large strains the flocculatedstructure of soil is broken and ultimate strength will be equal for both dry and wetsides.*

EFFECT ON SHEAR STRENGTH



SUMMARY

	DRY SIDE	WET SIDE
STRUCTURE	MORE RANDOM	MORE ORIENTED
PERMEABILITY	MORE PERMEABLE	LESS PERMEABLE
COMPRESSIBILITY	MORE COMPRESSIBLE IN HIGH PRESSURE RANGE	MORE COMPRESSIBLE IN LOW PRESSURE RANGE
SWELLING	SWELL MORE	SHRINK MORE
STRENGTH	HIGHER	LESSER

SHALLOW SURFACE COMPACTION

- Soil compaction achieved by diff means of Tamping, Kneading, Vibrating or impact
- Cohesive soil- Principle of tamping, kneading, impact
- Cohesionless soil- vibration, tamping, kneading
- Equipment available based on the above principle are rollers, tampers and rammers
- These equipments are used on the surface of the ground to improve the material property to a limited depth from ground surface are termed as **Surface compaction equipments**
- Large depth- heavy tamping also named as dynamic compaction, dynamic consolidation or dynamic pounding

❖SMOOTH WHEEL ROLLER

- 2 Types- one with 2 large wheels in the rear and a smaller single drum in the front

- -large single drum in the front and rear
- Static or vibratory type
- Self propelled with arrangements to move back and forth

a. **Static roller-** limited effective depth of compaction

   - limited pressure on the soil due to large contact area

- Hence their use restricted to situations where thin layers or a surface zone to be compacted.
- Used in base subbase layers and subgrades
- Used in earth dams and embakement compaction

b. Vibratory roller

- Most effective in compacting clean granullar soils in fills or subgrades
- a separate motor driven eccentric load system is provided to cause high frequency, low amplitude oscillation of vibrating drum
- Performance of compaction depends on static weight frequency, amplitude of vibration and roller speed
- Maximum compactive effort– 25 to 50 Hz
- Normal roller speed 3 and 6 km/hr.
- In case of thick layers or difficult to compact – 3 to 4 km/hr recommended

❖SHEEPSFOOT ROLLER

- Called tamping foot roller, having projecting studs or feet on the surface of the roller
  compaction by tamping and kneading action
- Suited for cohesive soil
- When the roller is passed for the first time, the projection penetrate the soil layer and the lower portion is compacted.
- In successive passes, compaction is obtained in the middle and top portion
- This continually rising effect of the compaction is called **Walking out** off the roller
- Projections penetrate the soil layers during the rolling operation and cause compaction

- Drum mounted on steel frame which can be filled with sand or water to increse the weight
- depth of compaction depends on length of projection and weight of the roller
- Smaller rollers can compact layers of 15 cm thickness
- Heavy roller- 30 cm thickness
- In general thickness of the layer compacted kept more than 5 cm of the length of projection

advantages

- more suitable for cohesive soil
- Feet produces kneading action
- Increase in blending of soil
- Possible soil compaction over a wide range of moisture content
- Effective in breaking down of large number of pieces

Disadvantages

- Relatively slow operation
- Lower compacted density
- Large entrapped air
- Soft zonesare not revealed easily

❖GRID ROLLER

GRID ROLLER

- Intermediate between ssmooth wheel and sheepfoot rollers, with theor rotating wheels made of network of steel bars forming a grid with square holes
- Less kneading action
- High contact pressure
- More suitable for coarse grained soil

❖PNUEMATIC TYRED ROLLER


Modem instru-ment panel were indicators and switcher are easy to reach.
The ergonomic designed F/R handle, located on the right side of the operator's seat makes operation smooth and easy.
Muffler and exhaust pipe are hidden under the hood for best possible visibility backwards.
Highly efficient cooling system keeps the engine and hudraulic system at the right temperature also when running at full speed.
DYNAPAC
Scrapers combined with cocoa mats keep the tyres clean and reduce the risk of picking.
Unique modular ballast system gives direct visual control of the wheel loads.
Ballast cartridges means less time and money spent on loading and unloading ballast in the form of sand and water.

PNUEMATIC TYRED ROLLER

- Versatile equipmement
- Effective for cohesive soils and cohesion less soil

Including sand, gravel, clayey sand, silty sand etc

The compaction primarily produced by kneading action

- Some designs provide "**wobble wheel effect**" to increase Kneading
- These rollers are outfitted with a weight box between two axles so that total compaction load can be easily varied
- 7 to 13 wheels are mounted in two rows and spaced so that the wheels of the rear row track in the space between those of the front row

- Such an arrangement does not create ruts and leave uncompacted areas
- Available in wide range of load sizes
- Heaviest having capacity of about 1800 Kn . However 450 Kn range is in common use
- Roller speed 6 to 12km/hr
- Advantages-Heavier weight, they require less no of passes, permit thicker lifts
- Compared to sheepsfoot roller , these rollers leave a smooth final surface

❖OPERATIONAL ASPECTSOF SHALLOW COMPACTION

Operating frequency

- Frequency of vibration – 25 to 30 cycle per second(HZ)
- However the compactive effort does not appear to varry significantly in the range of 25 to 50 HZ
- Combination of large amplitude and frequency just over the resonance frequency(25 HZ) gives better compaction and depth effect than the combination of high frequency and small amplitude

Number of passes

- 4 to 6 passes for the economical use of vibratory roller
- In saturated sands- 15 to 20 passes
- for static rollers equipped with sheepsfoot the minimum no of passes usually 4 to 8

Compaction at freezing temperature

- Frozen soils are difficult to compact effectively since they are strongly bonded
- If winter compaction is unavoidable , following strategies are adopted:
- Use dry coarse materials for construction(crushed rock or coarse gravel)
- If fill can be obtained in the borrow area in an unfrozen state, place and compact without delay.
- 10 degree C Gravel may freeze to a depth of 50 mm within two hours
- Recompact and regrade the surface during the following summer after the entire fill has thawed
- Adding calcium chloride helps to lowering the freezing point assist the compaction, since there is no unwanted side effects with resopect to env or eng properties

special considerations

- Partially saturated cohesionless soils have apparent cohesion because the surface tension forces in the porewater cause suction which increases the frictional resistance against compaction.
- Therefore better to compact these soils when they are completely dry or fully saturated
- Knowing the production rate (compaction capacity) assist in the selection of economical compaction equipment

$$p = \frac{Best}{n} 1000$$

$$p = \frac{Best}{n} 1000$$

PP= production rate, m3/h

B= drum width, m

e= efficiency

S= speed

t= layer thickness, m

n= no of passes

EXPLOSION

- Charges should be timed to explode such that the bottom of the layer being densified upwards in a uniform manner.
- The upper most portion of the stratum may be less densified which my be compacted by vibratory rollers.
- https://youtu.be/4PZcTeA6R18

EXPLOSION

- ADVANTAGES
- Less time , labor and expenses
- Needs no special equipment and could effectively used for densifying soil at a great depth.
- used to compact a large volume to a substantial depth up to 20 m and in small areas where the use of other method would be impractical
- Relative densities of the order 70 to 80% can be achieved
- In remote areas where vibrations are favorable , the technique may be proved most cost effective.

EXPLOSION

- DISADVANTAGES
- Non uniformity
- Potential adverse effect on adjacent structures
- Danger associated with the use of explosives in populated areas
- Very fine grained soils cannot be compacted by this method.
- Maximum compaction is obtained only when the soil is dry or completely saturated
- In partially saturated soil due to capillary tension between the soil grin , less densification is achieved.

VIBRO-COMPACTION
AND
VIBRO DISPLACEMENT

METHODS FOR GROUND IMPROVEMENT

1. VERTICAL DRAINS
2. SOIL NAILING
3. STONE COLUMNS
4. VIBRO COMPACTION
5. DYNAMIC COMPACTION

VIBRO COMPATION

- It is a ground improvement process for densifying loose sands to create stable foundation soils.
- The action of the vibrator, usually accompanied by water jetting, reduces the inter-granular forces between the soil particles, allowing them to move into a denser configuration, typically achieving a relative density of 70 to 85 percent.
- Compaction is achieved above and below the water table.

- Vibro -compaction works by using a vibrator suspended from a crane to penetrate to the design depth. Water jetting is often used to aid penetration. The energy of the vibrations reduces the forces acting between the soil particles which allows them to become denser.
- The new density or compactness attained is permanent and not reversible.
- The effectiveness of these methods decrease with increase in the percentage of fines in the soil.
- Three methods which are in use are blasting, vibratory probe , vibratory compactors.

1.BLASTING

- In this technique a certain amount of explosive charge is buried at a certain depth of cohesion less soil.
- The shock wave produced by blasting cause densification.
- The dynamite is wrapped in water proof bundles and lowered through casing.
- It is one of the most economical method.
- Disadvantages–non uniformity, danger associated with the use of explosives.

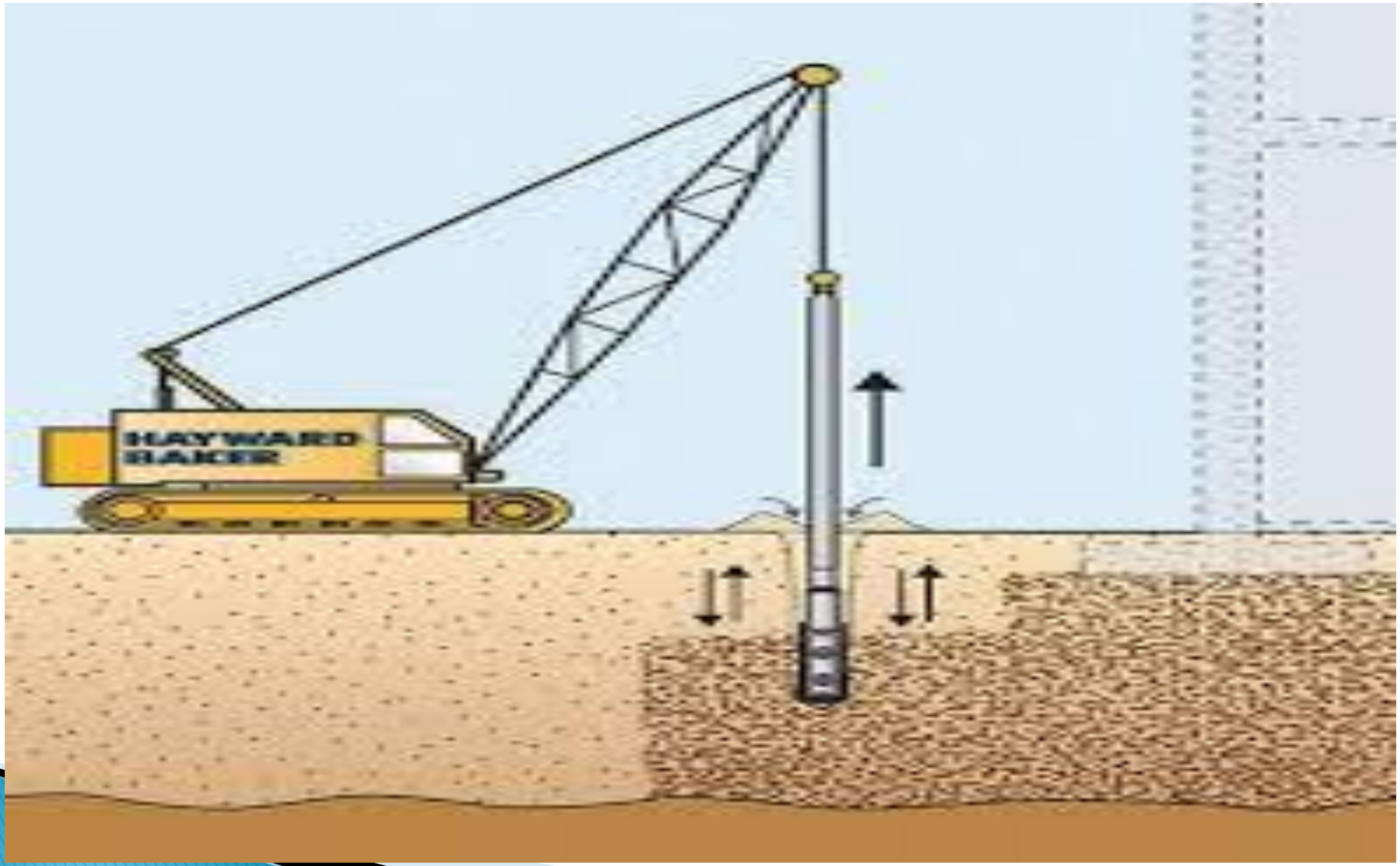
2.VIBRATORY PROBE

- Vibrodriver with open ended steel tubular probe of 760mm dia and 15m length
- Vibration: 15Hz
- Held 30-60 seconds before extraction
- Spacing 1-3m- square pattern
- Influence area- 1m cylinder and 1m deeper than probe depth
- Great depths
- Saturation preferrable
- Less cost
- More useful in offshore locations
- faster

3.VIBRATORY COMPACTORS

- Vibrating drums, pneumatic tyred rollers, vibrating plate etc.
- 1500-2500 cpm
- 3-6 km/hr
- Rel.densities 85-90%
- Lift thickness, roller type and soil type should match

- Vibro-compaction is most successful in loose sandy soil and is not applicable to clays.
- Relative densities up to 85% can be achieved.
- It is less hazardous. Because the magnitude of vibration felt on adjacent site is less.



Vibro-displacement

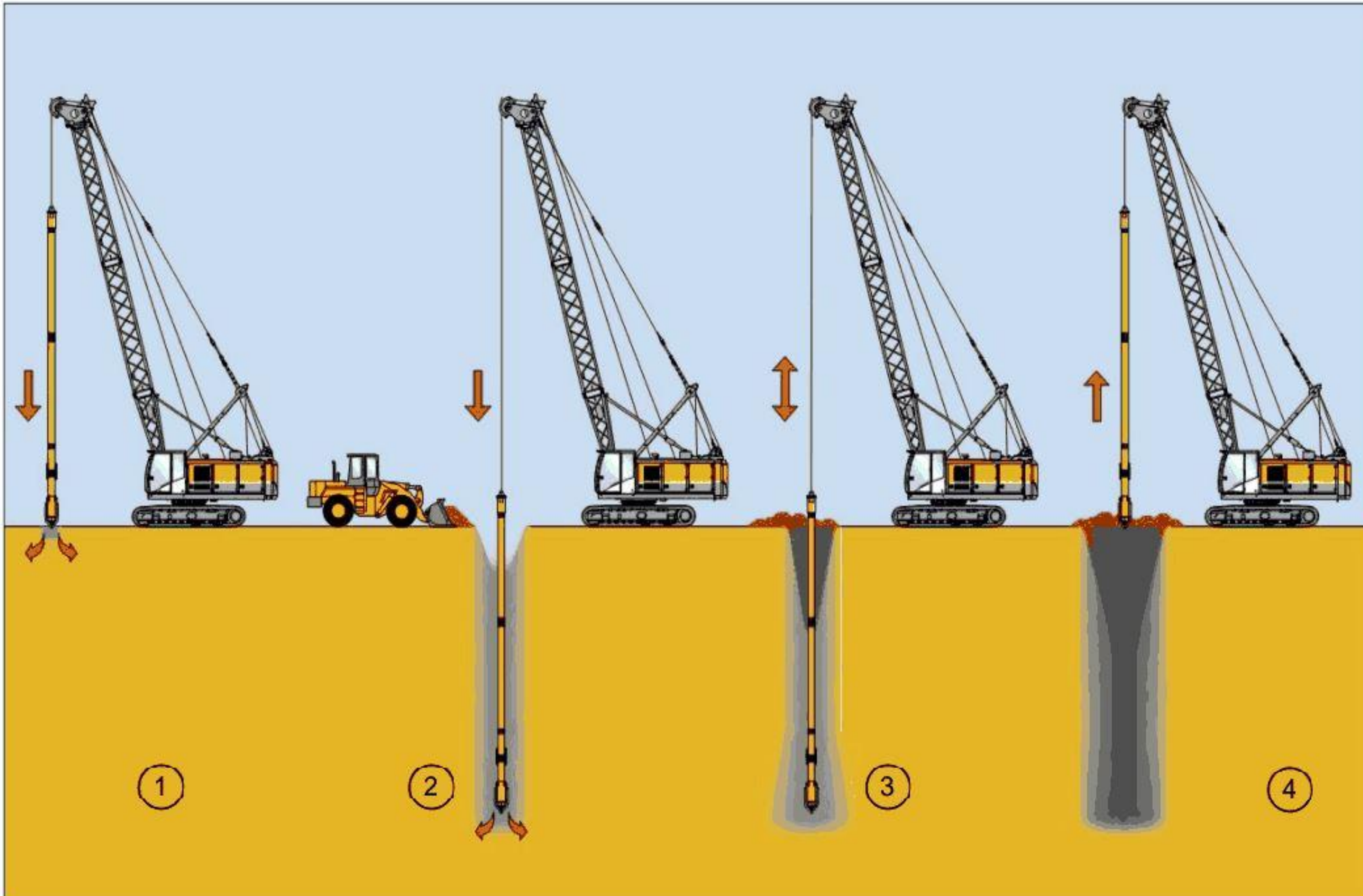
- Similar to vibro-compaction.
- The vibrations are supplemented by active displacement of soil and by backfilling the zone by suitable material.
- Various methods used are displacement piles, vibroflotation , sand compaction piles , stone columns.

1.DISPLACEMENT PILE

- Simplest vibro-displacement techniques
- Driving piles into sand to densify it- usually timber piles
- Most effective in cohesionless sands above WT
- Effect decreases with increase in fines content and decrease in permeability
- Effective to a distance upto 8d from center of pile.

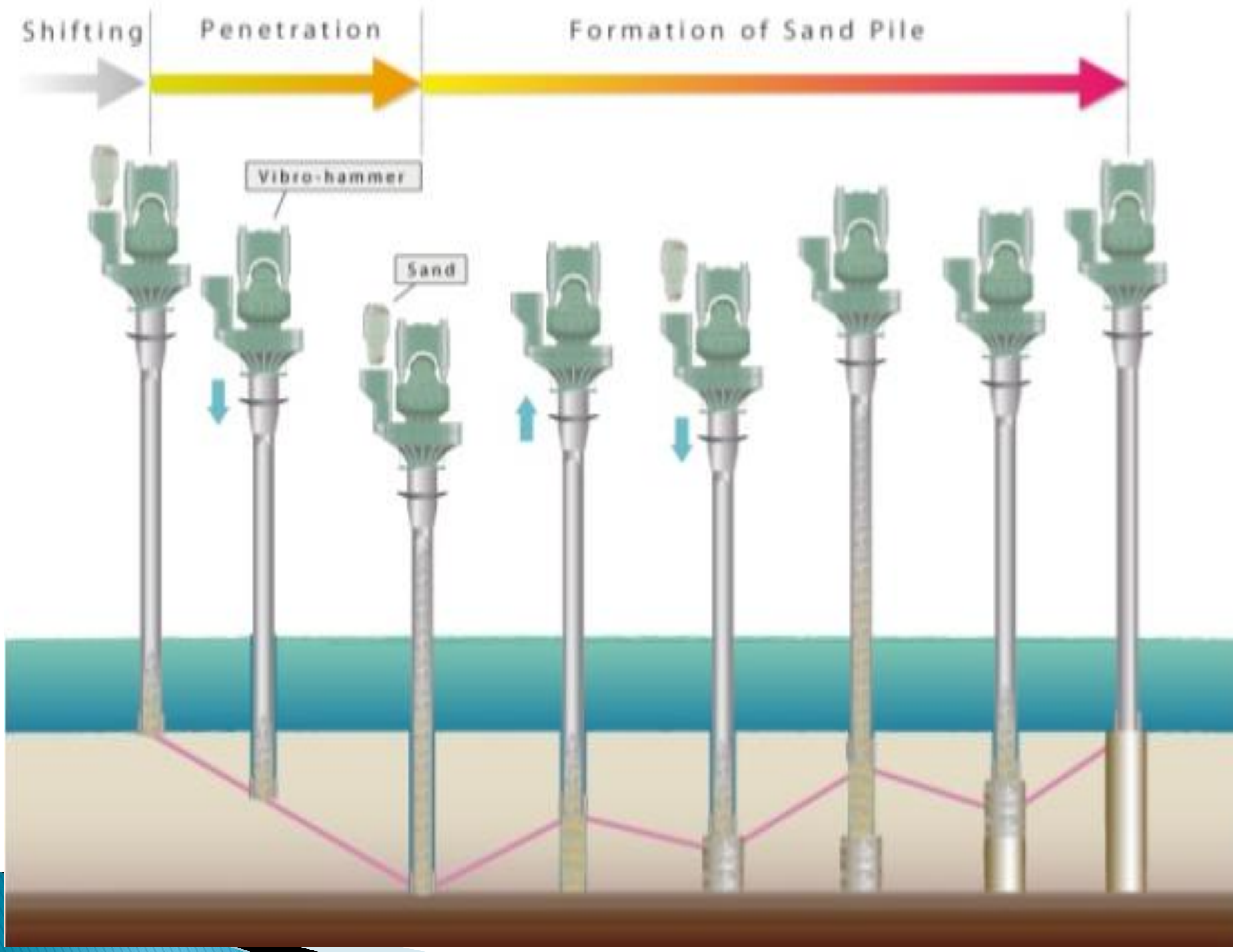
2.VIBROFLOTATION

- Mainly for cohesionless soil .
- Equipment: Vibratory probe, crane, feeder, water pump, power supply
- Probe dimensions : dia 0.3-0.5 m
- 4 stages
- Water is pumped at 225 to 300 liters/min at a pressure of 400 to 600 kPa.
- Continuous or discrete monitoring is required.


1
2
3
4

3.Sand compaction piles

- Also called a vibro-composer method.
- Effect decreases rapidly outwards and vertically upwards.
- Economical for depth up to 15 m.
- Square or rectangular pattern.
- Pile spacing varies from 2.5 to 4.


Shifting
Penetration
Formation of Sand Pile
Vibro-hammer
Sand

4.Stone columns

- These are also called as granular piles.
- It is installed mostly using vibration techniques.
- A cylindrical vertical hole is made and gravel backfill is placed into the hole in increment and compacted by a suitable device.
- This result in densely compacted stone column of certain depth.