23CE707: GROUND IMPROVEMENT TECHNIQUES

Topic: Mechanical Modification

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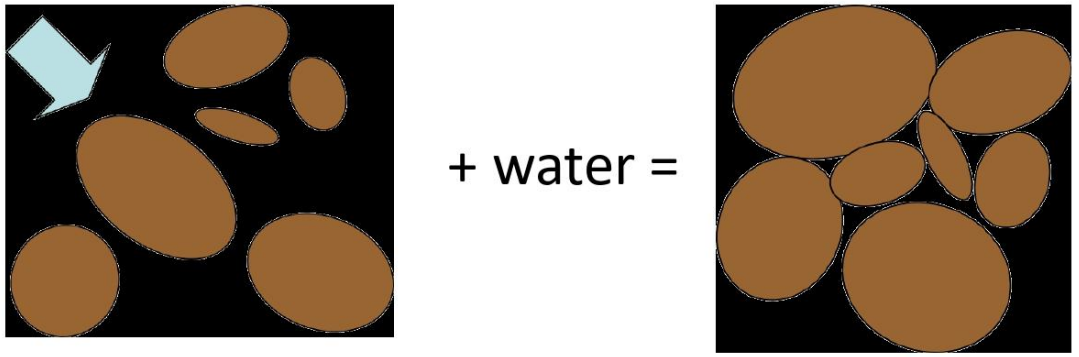
compaction

- A simple ground improvement technique, where the soil is densified through external compactive effort.
- By these compaction the improvement of soil properties and increasing the stability of the soil.
- Many types of compacting equipment are available now a days for compacting different types of soils.
- This is accomplished by applying static or dynamic loads to the soil.

Compaction image



Advantages of compaction

- Increases shear strength
- Reduces compressibility
- Reduces permeability
- Reduces settlement of foundation
- Increases slope stability.

Choice of method

- Type of soil
- Type and degree of improvement required
- Cost
- Available equipment
- Time
- Damage to adjacent structures
- durability

Factors affecting compaction in the field

- Compactive effort
- Moisture content
- Soil type
- Layer thickness
- Contact pressure
- Number of rollers passes
- Speed of rolling

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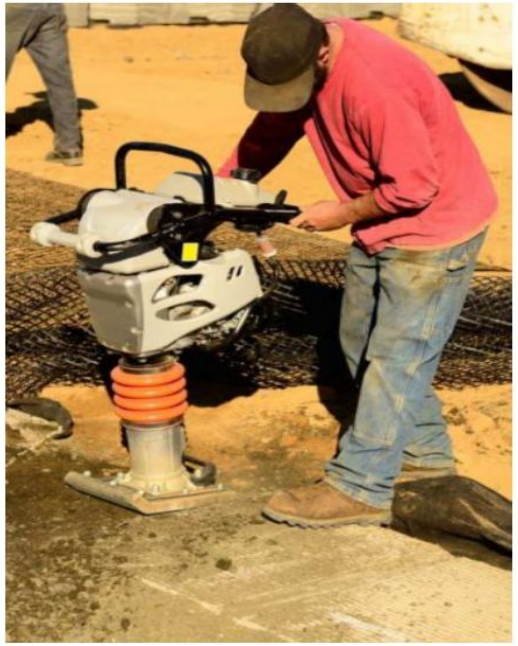
Types of action

- The maximum compaction is done by
  - Ramming
  - Vibration
  - Static roller

Rammers

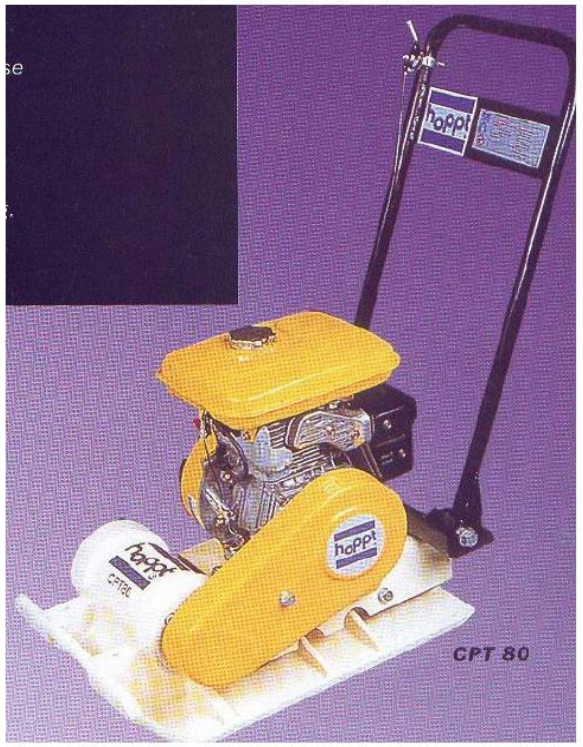
- This compaction equipment is light weight and easy to handle and these rammers are mainly
- Rammers are most suitable for cohesive and semi-cohesive soils.
- Its base dimensions are 15 cm x 15 cm or 20 cm x 20 cm or more
- Frequency ranges of blows are 500-750 per minute.
- Maximum 220mm thickness of layers can be compacted by using these rammers.
- The weight of the rammer is about 30 kg to 1 tonne.

- Rammer compacts surface through impact and vibration.
- Rammers are used at the difficult area where other types of equipment are not able to operate.



Vibrating plate compactors

- The weight of this compactor is 100kg to 2 tonnes and the plate areas between 0.16 sq.cm to 1.6 sq.cm.
- Used for compacting small areas.
- They usually travel about 0.7 km/h.
- These are used for small areas like parking slots etc.



Vibratory compaction equipment

compactor as per the requirement.

2.4.2 Vibratory Compaction Equipments

Vibratory compactors may be categorized into the following groups (Sharma, 1988):

(*i*) Tandom vibratory compactors
(*ii*) Towed vibratory compactors
(*iii*) Towed sheeps-foot or Tamping-foot vibratory compactors
(*iv*) Self-propelled vibratory compactors
(*v*) Hand-guided vibratory compactors.

Tandom Vibratory Compactors: Two types of Tandom vibratory compactors are available, *viz.*, single-drum vibrating or double-drum vibrating. In the compactors with double-drum vibrating system two tandom wheels are provided with separate controlled vibrators in the front and rear rolls. Comparing single and double-drum vibratory compactors, the output of double-drum vibratory compactor is to be 80% more than the single-drum vibratory compactor. The double-drum vibratory type has an option to operate the single-drum or the double-drum.

Towed Vibratory Compactors: This type of compactor is especially used for compacting cohesive soils, fine and coarse grained mixed soil and rocky materials. The heavy type towed vibratory compactor is used in earth dam and embankment constructions. Because of the large amplitude, it shows more impact motion and therefore preferred for compacting cohesive soils, fine grained soils and mixed fine or coarse grained soils.

Towed Sheeps-Foot or Tamping-foot Vibratory Compactors: Towed sheeps-foot or tamping-foot vibratory compactor is useful in highly cohesive soils and soft rocks. The kneading and crushing effect of the feet improves the compaction performance. The compactors are provided

Vibratory compaction equipment

with sheeps-foot or tamping-foot vibratory equipment. Tamping-foot are larger than the sheeps-foot and hence has a more contact area.

Self-Propelled Vibratory Compactors: These compactors are available with a weight of 8 to 10 tons dead weight. In one type large vibratory steel roll in front and two rubber tyres at the rear. The rubber tyres may be smooth or with treads. The smooth one can be used for bituminous work and the treads one for earth compaction work.

In the other type, vibratory steel roll is in the front and two static steel rolls at the rear for multi purpose work.

Hand-Guided Vibratory Compactors: Compactors of this type have duplex or double vibratory compactors with dual roll vibration and dual roll drive. These vibrators are small in size and thereby enable cross country mobility and excellent gradeability. They have provision for dual roll drive. These are especially used for compacting trenches, slopes, packing lots, small repair jobs and sports grounds, *etc*.

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Rollers

- Sheep-foot roller
- Smooth drum roller
- Pneumatic-tire roller
- vibratory rollers

Compaction methods

- Laboratory procedure
- Shallow surface compaction
- Deep compaction techniques

other names

- Kneading
- Tamping
- Vibrating
- impact

Laboratory procedure

Parameter	Standard Proctor	Modified Proctor
Volume of mold (m^3)	9.44×10^{-4}	9.44×10^{-4}
Mass of hammer (kg)	2.5	4.54
Height of fall (mm)	305	457
Number of layers	3	5
Number of blows	25	25

Shallow surface compaction

Sheep foot roller

- It is also called tamping foot roller
- Suitable for predominantly clayey soils, not for coarse grained soils.
- Tamping and kneading action
- Protruding studs /feet that penetrate into soil
- Contact pressure: 1500-7000 kPa.
- Usual roller speed 3-6km/hr
- Width of drum is 1.22 m to 1.98 m and Dia of drum is 1.02 m to 1.83 m.
- Weight of empty roller is 1.6 to 7 tonns
- The number of passes necessary for this type of roller to obtain the required densities must be determined for each type of soil encountered.

- Advantages over smooth wheeled rollers
  - –More suitable for cohesive sols
  - –Kneading action
  - –Increased blending(mixing things together)
  - –simplification of adding water or drying as needed.
  - –Effective in breaking down rock pieces
- Disadvantages:
  - –Slow operation
  - –Lower compacted density
  - –Large entrapped air (voids present in the soil due to insufficient compaction)

Sheep foot roller

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Smooth drum roller

- Used primarily for granular soils.
- Probably its most effective use in subgrade work is in the final finish of a surface.
- 3-6km/hr speed
- Large contact area hence less pressure(300-400kPa)
- These rollers have one large steel drum in front and two steel drums on the rear. The gross weight of these rollers is in the range of 8-10 tonne.
- The other type of smooth wheel roller is called Tandem Roller, which weighs between 6-8 tonne.
- About 8 passes are adequate for compacting 20 cm layer.

Smooth drum roller

Advantages of Single Drum Roller

- The single drum roller has its unique advantages. Since it's smaller than the double drum roller, its sleek shape can guarantee that it can work in narrow and tight area, which the double drum roller can't do.
- The single drum roller is perfect for preparation work before paving road. Using a single drum roller, we can easily compact and flatten the ground of sidewalk or driveway. Therefore, single drum vibratory roller is very good at highway paving and setting foundations for some buildings.
- The front of single drum roller is heavier, The drum needs to be giant and weighs much to compact the ground. Besides, due to the back tires, the roller will have better quality than double drum one.

Double Drum Roller

- The biggest difference between single drum vibratory roller and double drum vibratory roller is that it has two drums instead of tires behind.
- A double drum roller can flatten ground in front of and behind the roller at the same time, while the single drum one can only compact on the front at one time.

Advantages of Double Drum Roller

- The most significant advantage of double drum roller is efficiency. After all when you are operating the roller, two drums will work on the same time.
- It's double area when compared with single drum roller. That will certainly improve working efficiency and economize manpower.
- Because of better power and efficiency, double drum roller can work greatly on asphalt.
- The machine can flatten ground of highway with fast speed and high accuracy.

Pneumatic tyred roller

- Suitable for both cohesive and cohesion less soils
- Pneumatic tyred rollers are used in both earthwork and bituminous work
- they can compact the layers with uniform pressure throughout the width.
- Front and rear wheels not in alignment for better efficiency
- Speed 6-12 km/hr
- Smoother finish
- Lift thickness: 15-30 cm based on roller weight
- Heavier in weight hence lesser no; of passes required

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Pneumatic tyred roller

Advantages

- They provide a more uniform degree of compaction than steel wheel rollers.
- They provide a tighter, denser surface thus decreasing permeability of the layer.
- They provide increased density that many times cannot be obtained with steel wheeled rollers.

Disadvantages

- The individual tire arrangement may cause deformations in the mat that are difficult or impossible to remove with further rolling. Thus, they should not be used for finish rolling.
- If the HMA(Hot mix asphalt) binder contains a rubber modifier, HMA pickup (mix sticking to the tires) may be so severe as to warrant discontinuing use of the roller.

Pneumatic tyred roller

Grid rollers

- Intermediate between smooth wheeled and sheepfoot rollers
- Wheels made of steel bars forming a grid with square holes
- Less kneading action but high contact pressure
- More suitable for coarse grained soils.
- operate at speeds between 5 and 24 kmph.

Grid rollers

Vibratory rollers

- Latest specifications of earthwork invariably recommend vibratory rollers. These rollers are helpful from several considerations like:-
- (i) Higher compaction level can be achieved with maximum work
- (ii) Compaction can be done up to greater depths
- Vibratory rollers are similar to smooth wheel rollers with the modification that the drum or drums are made to vibrate by employing rotating or reciprocating mass

Vibratory rollers

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Impact roller

- The latest compaction equipment are high-energy impact rollers, which use shaped (e.g., triangular ellipsoids or hexagonal).
- The high energy imparted by these systems allows them to achieve compaction at a faster rate and to greater depths.
- A comparison of different types of compaction equipment based on vertical settlement with number of passes is shown at upper left, demonstrating the superior effectiveness, both in terms of number of passes, and influence depth of high-energy equipment.
- 1.5 m thick square with rounded edges.
- Provides deeper 2-3m compaction.

Impact roller

Table 1.1 : Typical characteristics of impact and vibratory equipment for shallow compaction*

Types no. and name		Typical characteristics				
		Mass, t	Max. working speed, km/h	Vibrating frequency, Hz	Depth of lift, m	Number of passes
1	Vibrating hammer	0.3 – 0.1	-	7 – 10	0.2 – 0.4	2 – 4
2	Light vibrating plate	0.06 – 0.8	1	10 - 80	0.15 – 0.5	2 – 4
3	Light vibrating roller	0.6 – 2	2 - 4	25 -70	0.3 – 0.5	4 – 6
4	Heavy towed vibrating roller	6 – 15	8 – 10	25 -30	0.3 – 1.5	4 – 6
5	Heavy self-propelled vibrating roller	6 -15	6 – 13	25 -40	0.3 – 0.5	4 – 6
6	Impact roller	7	10 -14	-	0.5 - 3	Up to 30

TABLE 3.2A Applicability of Compaction Equipment

Equipment	Most-suitable soils	Typical applications	Least-suitable soils
Smooth wheel rollers, static or vibrating	Well-graded sand-gravel mixtures, crushed rock, asphalt	Running surface, base courses, subgrades for roads and runways	Uniform sands
Rubber-tired rollers	Coarse-grained soils with some fines	Road and airfield subgrade and base course proof-rolling	Coarse uniform cohesionless soils, and rock
Grid rollers	Weathered rock, well-graded coarse soils	Subgrade, subbase	Clays, silty clays, uniformly graded materials
Sheepsfoot rollers:			
Static	Fine-grained soils with more than 20% fines	Dams, embankments, subgrades for airfields, highways	Clean coarse-grained soils, soils with cobbles, stones
Vibrating	As above, but also sand-gravel mixtures	Subgrade layers	
Vibrating plate (light)	Coarse-grained soils, 4 to 8% fines	Small patches	Cohesive soils
Tampers, rammers	All types	Difficult-access areas	
Impact rollers	Wide range of moist and saturated soils	Subgrade earthworks (except surface)	Dry, cohesionless soils

Hausmann, M. R., "Engineering Principles of Ground Modification", p 27, McGraw-Hill Co., 1990. Reproduced by permission of McGraw-Hill Companies.

Deep compaction

Vibroflotataion Techniques

- Vibroflotation is a ground improvement technique used at a considerable depth that by using a powered electrically or hydraulically probe, it strengthens the soil.
- Vibroflotation can be obtained by using three different techniques:
- Vibro Compaction method- This method allows granular soils to be compacted. This method is only used to compact sandy soils.
- Vibro Replacement or displacement method- The technique is used to replace poor or inadequate soil material by flushing out the soil with air or water and replacing it with granular soil. This can be used in various soil types such as clay and sandy soils.

Vibroflotation

Suitable for granular soils and cohesive soils

Practiced in several forms:

- vibro–compaction
- stone columns
- vibro-replacement

Vibroflot (vibrating unit)

Length = 2 – 3 m

Diameter = 0.3 – 0.5 m

Mass = 2 tonnes

(lowered into the ground and vibrated)

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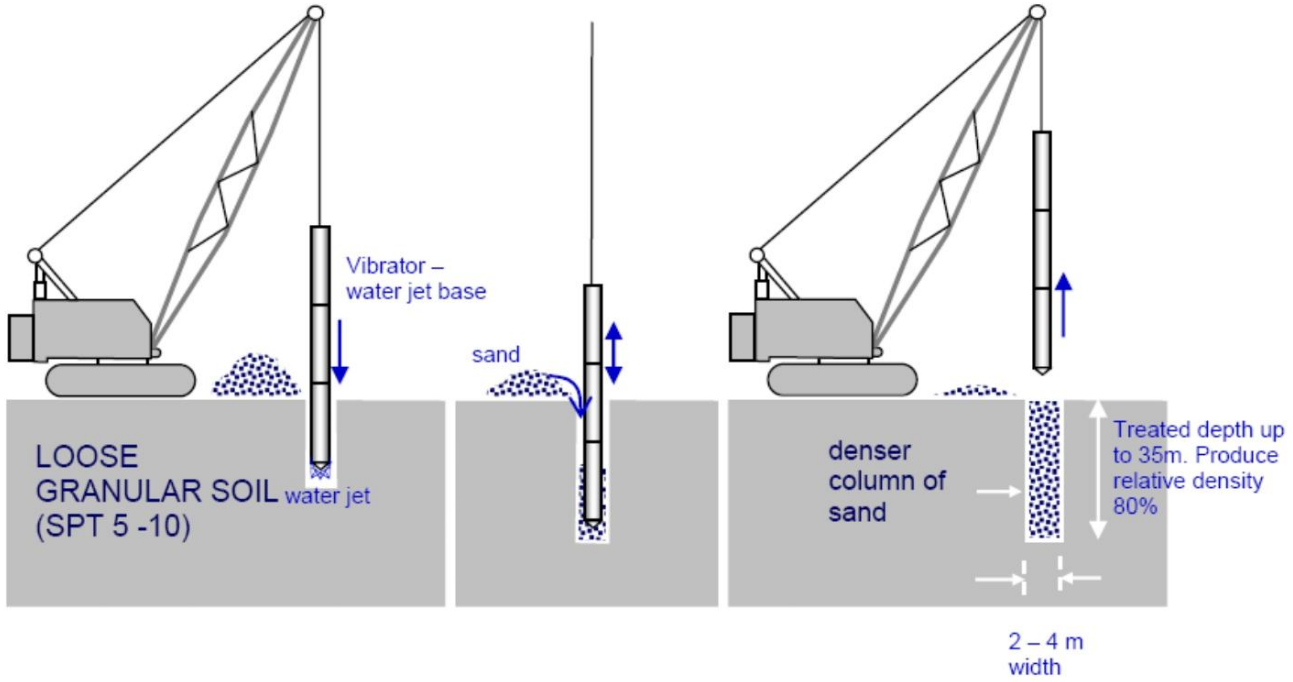


Figure 1.12 : Vibro compaction

Deep compaction techniques

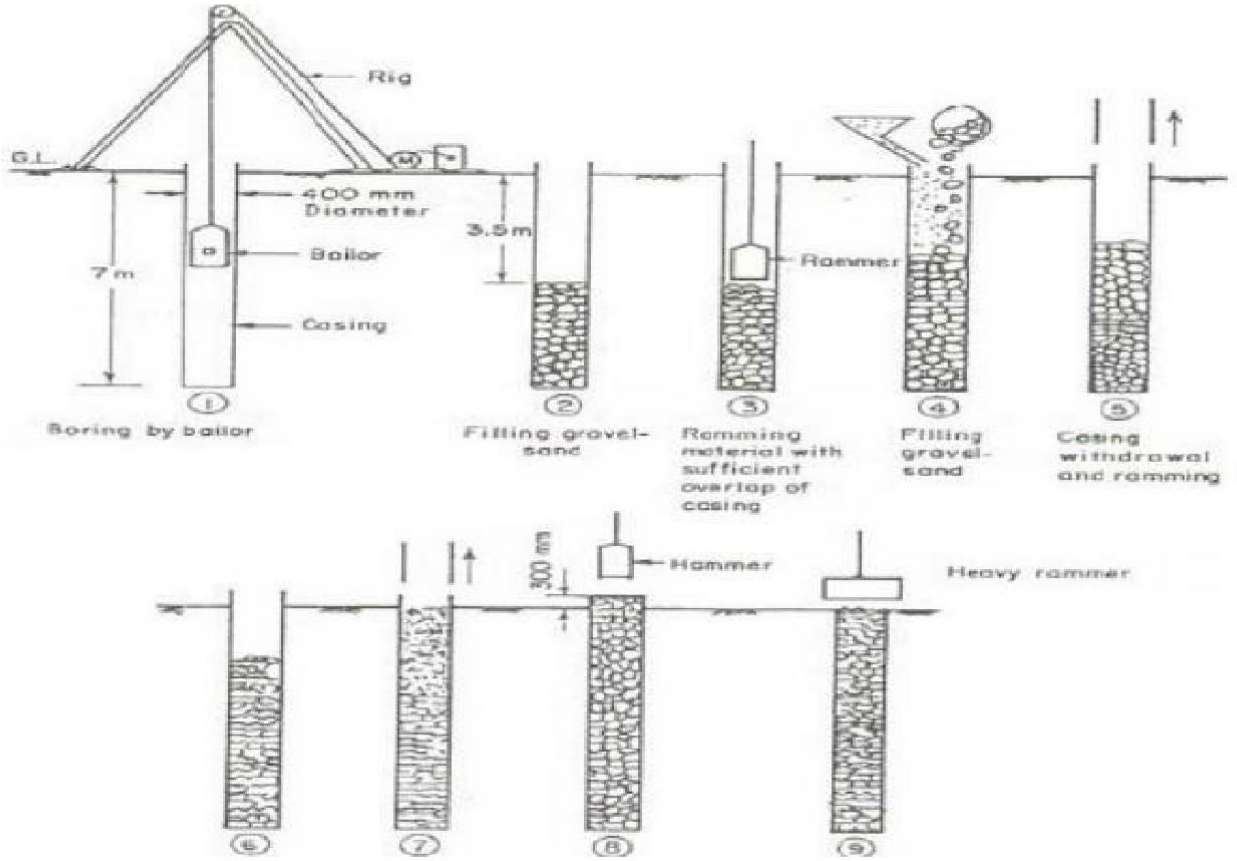
STONE COLUMNS

- Stone columns are a ground improvement technique to improve the load bearing capacity of the soil
- The stone column consists of crushed coarse aggregates of various sizes.
- Applicable to wide range of soils and Stone columns are best suited to cohesive soils.

Methods of installation

- Methods of installation Cased Borehole method/ Rammed stone column
- Vibration Methods - Vibrofloatation / Vibrocomposer

Cased Borehole Method/ Rammed stone column



Cased Borehole Method/ Rammed stone column

- Proposed by Datye and Nagaraju (1977) and developed by Nayke(1982)
- Uses a bored piling rig to dig the borehole and granular fill is placed and compacted in stages

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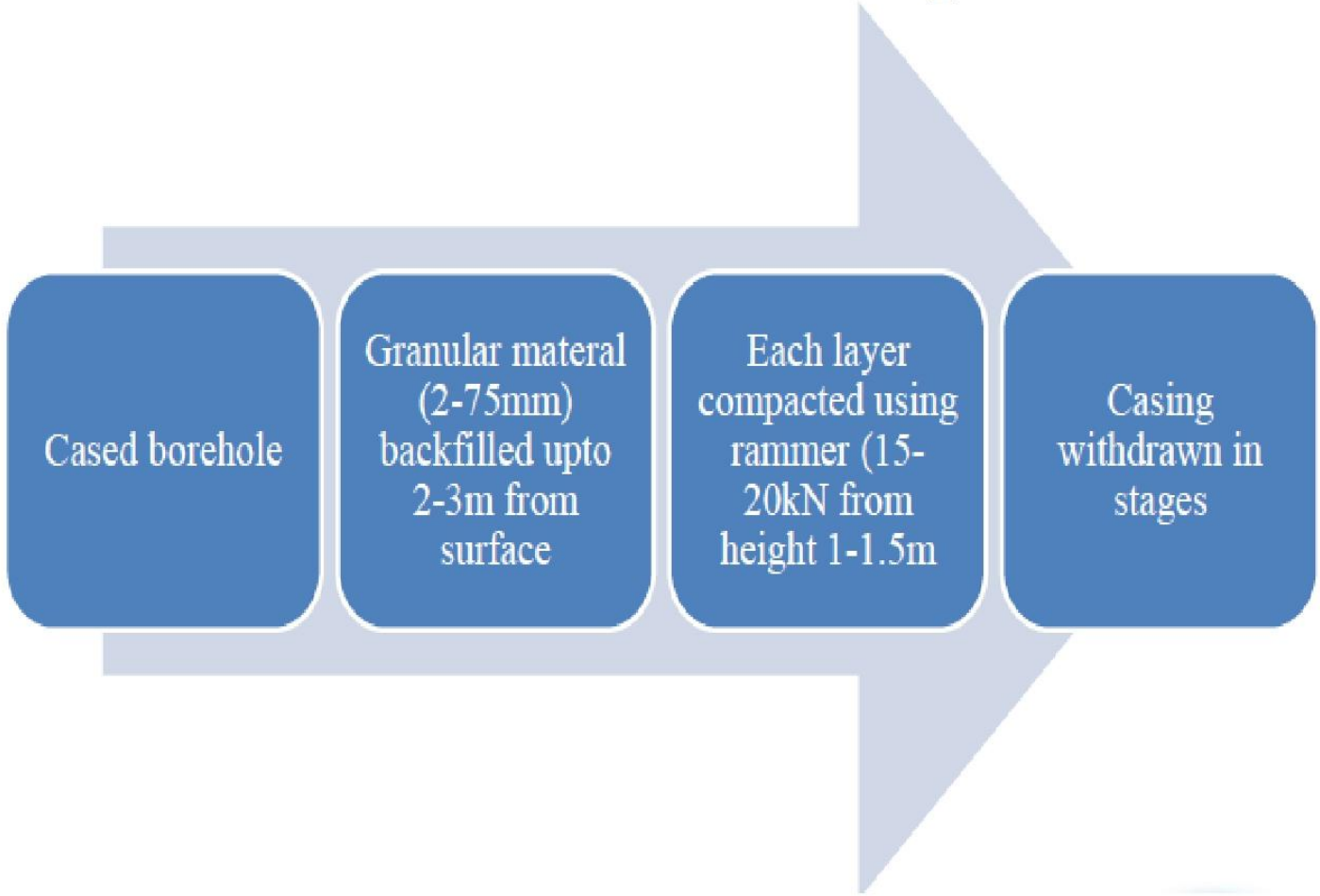
Cased Borehole Method/ Rammed stone column

- Rammer weighing 15 to 20 kN falling through height of 1 to 1.5 m for compacting stone aggregates.
- It is economical than vibrator compaction.
- In this method the bore hole is made by spiral auger and the bore hole is cleaned by using specially made tools.
- 2-75 mm size stone aggregate and 20-25% of sand is used.
- The aggregate and sand layers are placed alternatively with layer thickness of 300 to 500 mm respectively.

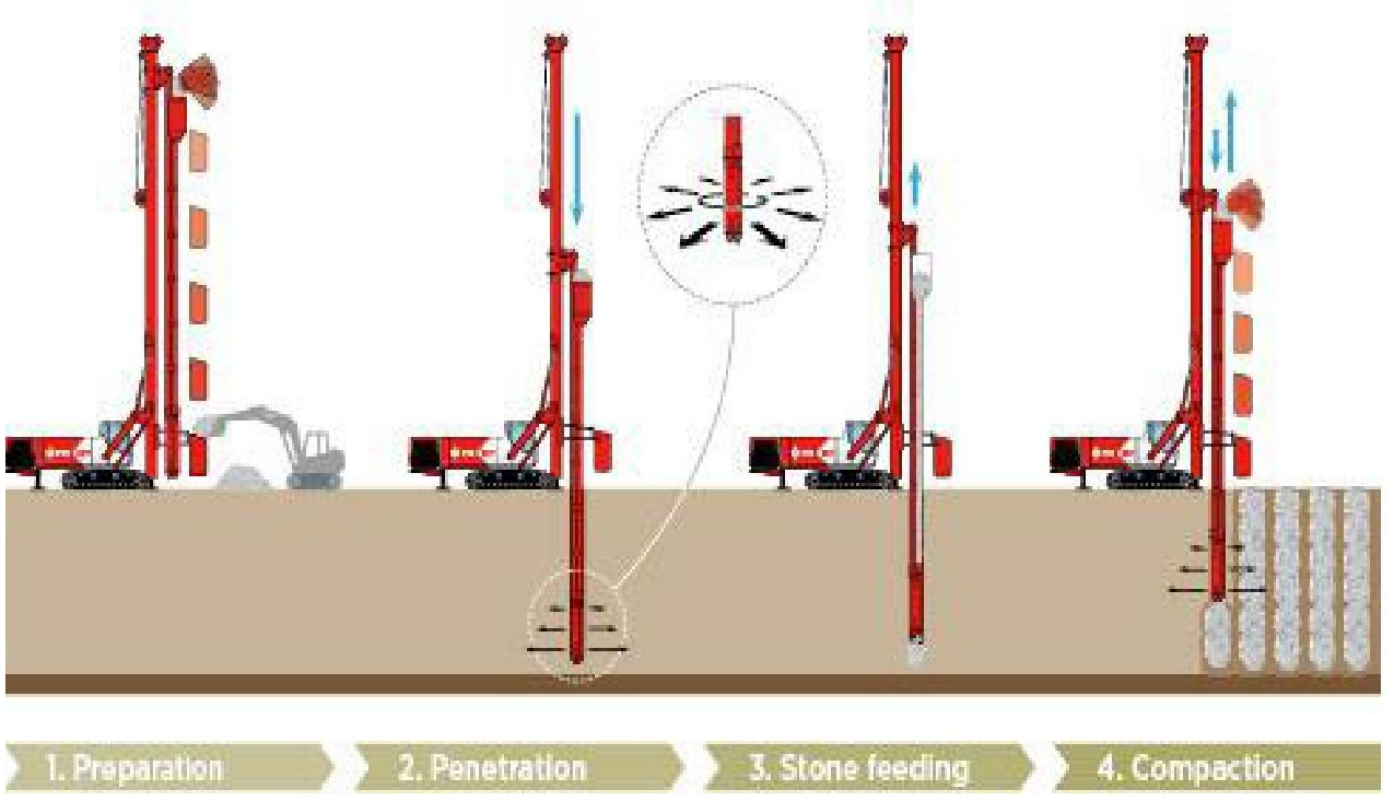
Rammed stone column- procedure



Vibro-floatation

- Formation of stone columns using a vibroflot is quite suitable techniques for improvement of cohesive soils.
- The vibroflot is allowed to sink in to the ground due to its own weight, associated by water or air as a flushing medium up to required depth.
- Water is used as a jetting fluid for fully saturated soils while compressed air is used for partially saturated soils.
- It simultaneously releases water from the lower jets which remove the soft soil directly under the vibrofloat nose forming a hole.

Vibro-floatation



APPLICATION OF STONE COLUMNS

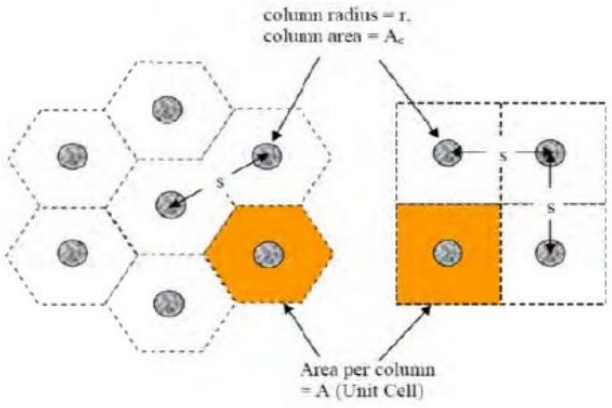
- Stone column acts as vertical drains and thus speeding up the process of consolidation.
- replaces the soft soil by a stronger material.
- Initial compaction of soil during the process of installation thereby increasing the unit weight.

Design Parameters

- Vibro-Displacement/Replacement Methods
  - Top/Bottom Feed methods
- Square or Rectangular Pattern:
  - Typical Spacing (S): 1.5 - 3.5m c/c
  - Triangular pattern: $D_e = 1.05\ S$
  - Rectangular pattern: $D_e = 1.13\ S$
- 0.6 -1.0 m Diameter Depending on the Material
- Length up to 20 m (Depends on the Strata)
- Crushed Rock Size: 20 - 75 mm
- Design loads: 20 – 50 tons

DESIGN CONSIDERATIONS

- *Stone Column Diameter*: The variation in pile diameter installed by vibroflot (diameter 300 to 500 mm) varies between 0.6m(stiff clays) and 1.1 m(very soft cohesive soils)
- *Pattern of arrangement* :



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- *Spacing:* the column spacing may broadly ranges from 2 to 3 m depending upon the site conditions, loading pattern, column
- *Replacement ratio: To quantify the amount of soil replaced by the stone, the term replacement ratio, as is used.* $a_s = 0.907 (D/S)2$
- where the constant 0.907 is a function of the pattern used which, in this case, is the commonly employed equilateral triangular pattern.
- *Stress Concentration factor:* The stress concentration factor, n, due to externally applied load σ, is defined as the ratio of average stress in the stone column σs ,to the stress σg, in the soil within the unit cell,

$$n=\sigma s / \sigma g$$

The value of n generally lies between 2.5 and 5 at the ground surface

- *Stress*: By assuming a triaxial state of stress in the stone column and both the column and the surrounding soil at failure, the ultimate vertical stress σ1, which the stone column can take, may be determined from the following equation:

$$\sigma 1/ \sigma 3 = (1+\sin \varphi s) /(1-\sin \varphi s)$$

where σ3 = lateral confining stress mobilized by the surrounding soil to resist the bulging of the stone column;

φs = angle of internal friction of the stone column

σ1/ σ3 =coefficient of passive earth pressure of the stone column.

- *Settlement: Consolidation settlement of the composite (treated) soil S, is given by:*

$$S= mv\sigma gH$$

where

mv = Coefficient of volume change

σg = Vertical stress in surrounding ground

H = Thickness of treated soil

- Aggregate: Crushed stone or gravel which is chemically inert, devoid of organic matter, hard etc are used for constructing the aggregate column. Well graded stones of 75mm to 2mm may be used.

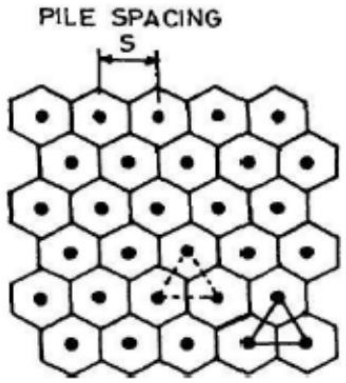

Fig. 7 Triangular pattern of arrangement

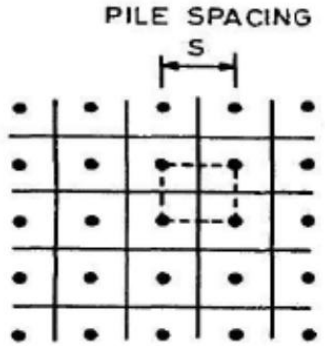

Fig. 8 Square pattern of arrangement

Disadvantages of stone columns

- Severe cracks could be seen in structures close by the stone column site due to the vibrations of 30-50Hz.

Deep dynamic compaction

- pounding the ground by a heavy weight
- Suitable for granular soils, land fills

Deep dynamic compaction

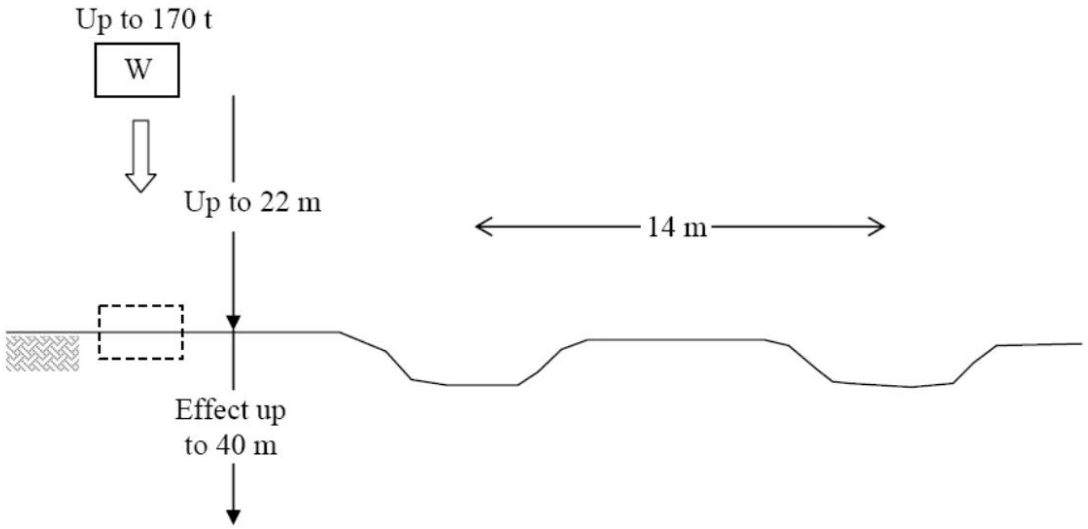

Figure 1.10 : Ground profile after tamping

Advantages of Dynamic compaction

- Compacts large areas of loose granular fills.
- Reduces the volume of landfill waste.
- Increases in situ density and the voids are collapsed.
- Increased bearing capacity.

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Disadvantages

- The impact of the weight in dynamic compaction sends waves of vibration through the ground. These vibrations could cause disturbance and possible damage of surrounding structures.
- Another disadvantage experienced when using dynamic compaction has occurred with combination soil profiles

In-place densification of granular soils

Blasting or by Explosives

- The range of soil grain sizes suitable for compacting by blasting method is the same as for Vibroflotation.
- In this method, the compaction is achieved by successive detonations of small explosive charges in saturated soils.
- Relative densities of 70 to 80 % upto a depth of 20 to 25 m can be achieved.

Blasting or by Explosives

- Explosive charges (60 % dynamite, 30% special gelatin dynamite, and ammonite are most commonly used) are placed at about 2/3 times the thickness of the stratum to be densified.
- The spacings of the charges vary from 3 to 8 m.
- Three to five successive detonations of several spaced charges are usually required to achieve the desired compaction.
- The shock waves due to blasting cause liquefaction of the saturated sand, followed by densification.
- Practically no compaction is achieved in the top 1 m and so this zone usually needs recompaction by rollers.

Blasting or by Explosives

The relation for the weight of charge and the sphere of influence for compaction can be given by:

$$W = CR^3$$

Where W = Weight of charge

R = Sphere of influence

C = Constant (0.0025 for 60 % dynamite)

If blasting is used in dry or partially saturated soils, preflooding is desirable.

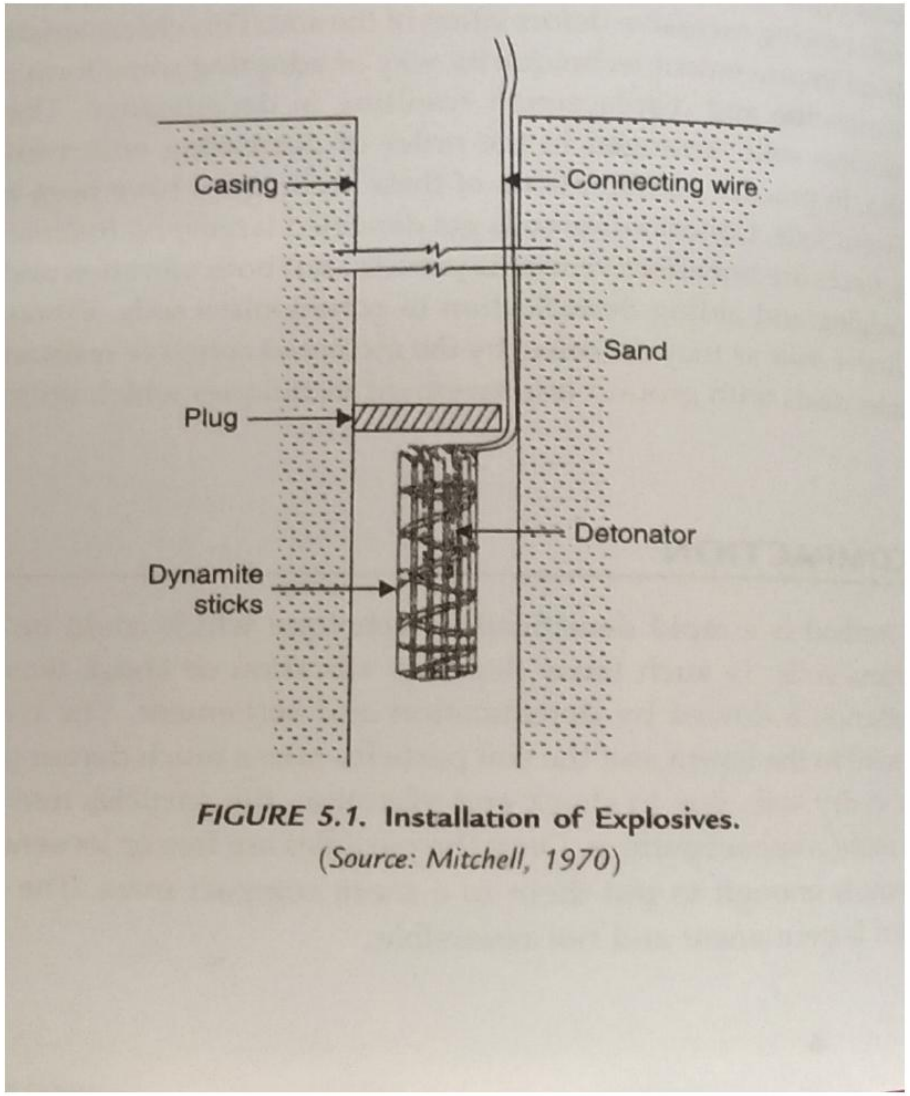

FIGURE 5.1. **Installation of Explosives.**
(Source: Mitchell, 1970)

Procedure of the blasting for ground improvement

- Series of boreholes are drilled and Pipe of 7.5 to 10 cm is driven to the required depth
- The detonator and the dynamic sticks are both enclosed and lowered through casings
- Casing is withdrawn and a wad of paper or wood is placed against the charge of Explosive (To protect it from misfire)

- Blasting is more effective in loose sands that contain less than 20% silt and less than 5% clay
- The blasting is done in stages. Repeated shots are more effective than a single larger one.
- The top surface up to 1m gets disturbed and needs surface compaction. Although blasting is quite economical, it's limited by several considerations as it produces strong vibrations that may damage nearby structures or produce significant ground movements.

Compaction quality control measurements

- Moisture control measurements
- In situ density measurements
- Nuclear moisture density methods
- Hilf's method

Thank You..