SHALLOW COMPACTION/DENSIFICATION

PRINCIPLE

Shallow Densification: Principle

In soil mechanics shallow densification or compaction means press the soil particles tightly together expelling air from the void spaces (reduction in void ratio)

Consolidation also results in reduction in void ratio but consolidation and compaction are not the same

Compaction is instantaneous and consolidation is slow

Saturation is the essential condition for consolidation which is not for compaction

Shallow Densification: Principle

Compaction increases soil's density and produces three important effects:
An increase in soils shear strength
A decrease in future settlement of soil
A decrease in its permeability

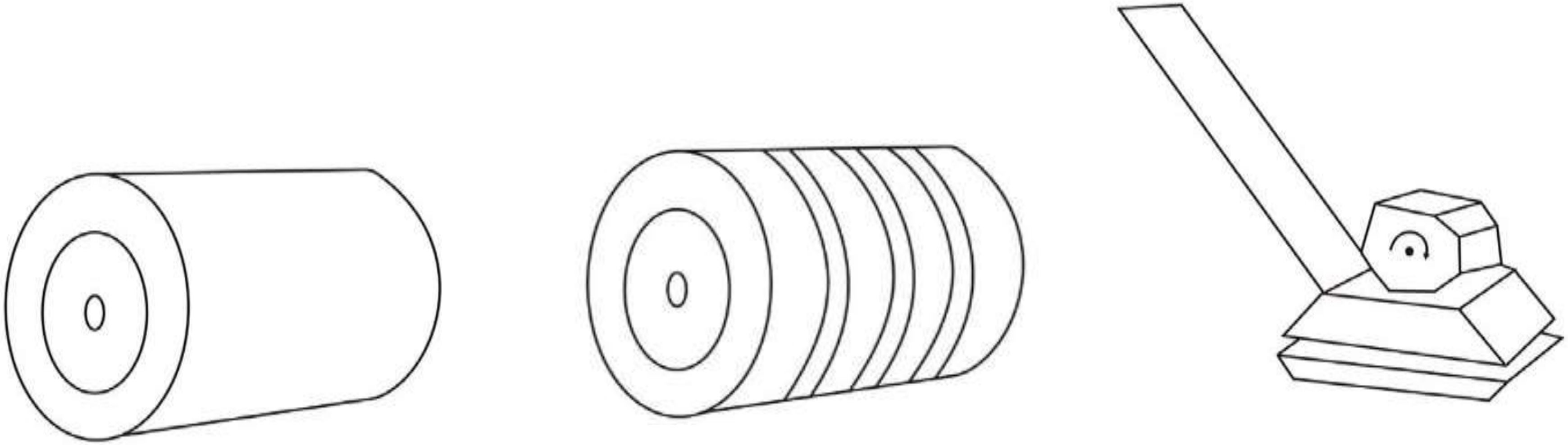
These three effects are beneficial for the construction of various types of earth structures namely, highways, airfield, earthen dam etc

Greater the compaction the greater is the benefits

Compaction is the cheap and effective way for improvement of soils properties

Shallow Densification: Principle

Conventional –use of roller or plates to repeatedly apply static pressure, kneading action or vibration on ground surface to densify geo-materials



Shallow Densification Methods

Roller are larger and heavier than plate compactors and therefore they are commonly and efficiently used for large area compaction

In constraint areas or unstable edges rollers are not suitable . Under such conditions, plate compactors are used.

Application: conventional compaction has been used for earthworks, such as roads, embankments, dams, slopes, and parking lots and sport field

Shallow Densification

Advantage:

Construction equipment is readily available.

It is a well established ground improvement method that has long history and extensive knowledge in the industry.

Limitations:

The depth of improvement is limited, mainly used for fill and not for insitu natural geo-materials, geo-material should be within the moisture content close to the optimum moisture content to be more effective, it is challenging to achieve uniform compaction of geo-materials in a large area

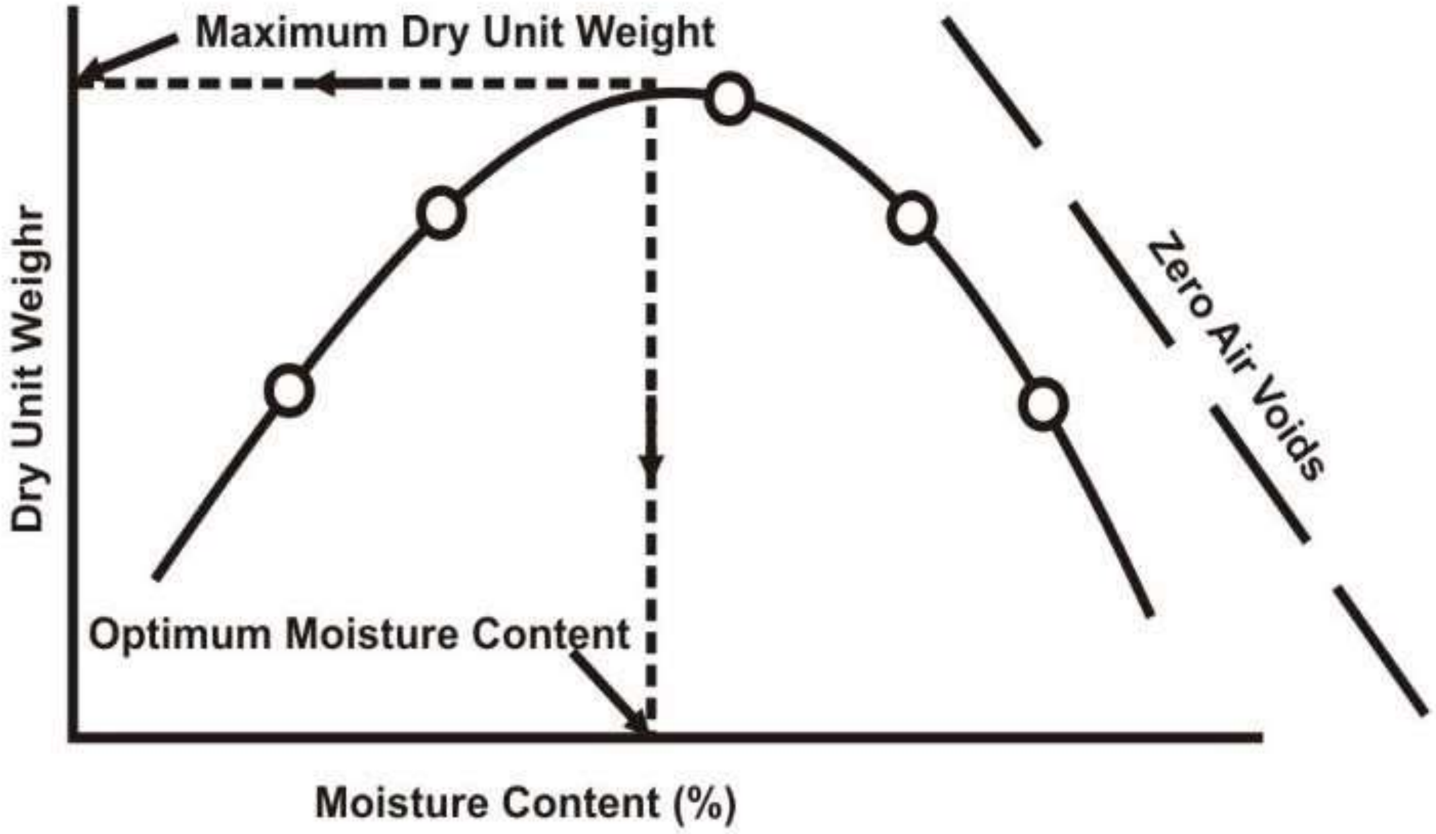
SHALLOW DENSIFICATION

Compaction is quantified by its dry unit weight, which can be computed in terms of bulk unit weight and moisture content

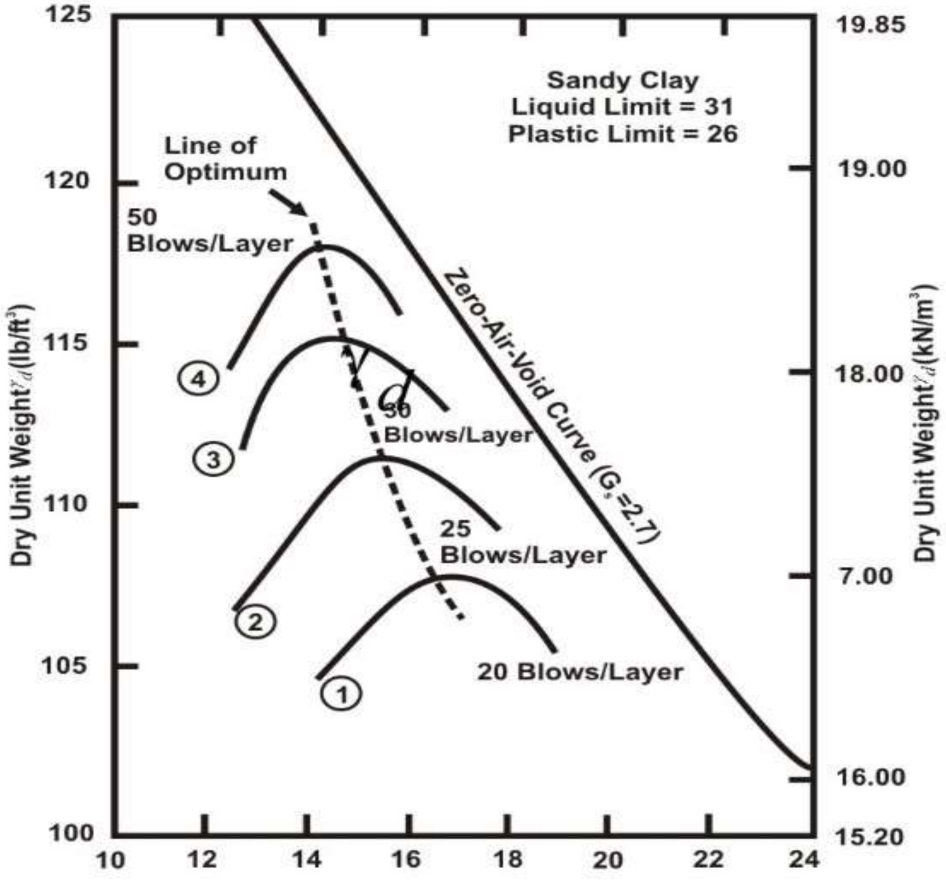
$$\gamma_d = \frac{\gamma}{1 + w}$$

In most cases dry soil can be best compacted if certain amount of water is added to it. Water acts as a lubricant and soil particles to be packed together. If, however, too much of water is added it results a lesser density. Thus for a given compactive effort there is a particular moisture content at which the dry unit is the greatest and compaction is the best. This moisture content is called 'optimum moisture content' and the associated dry unit weight is known as the maximum dry unit weight

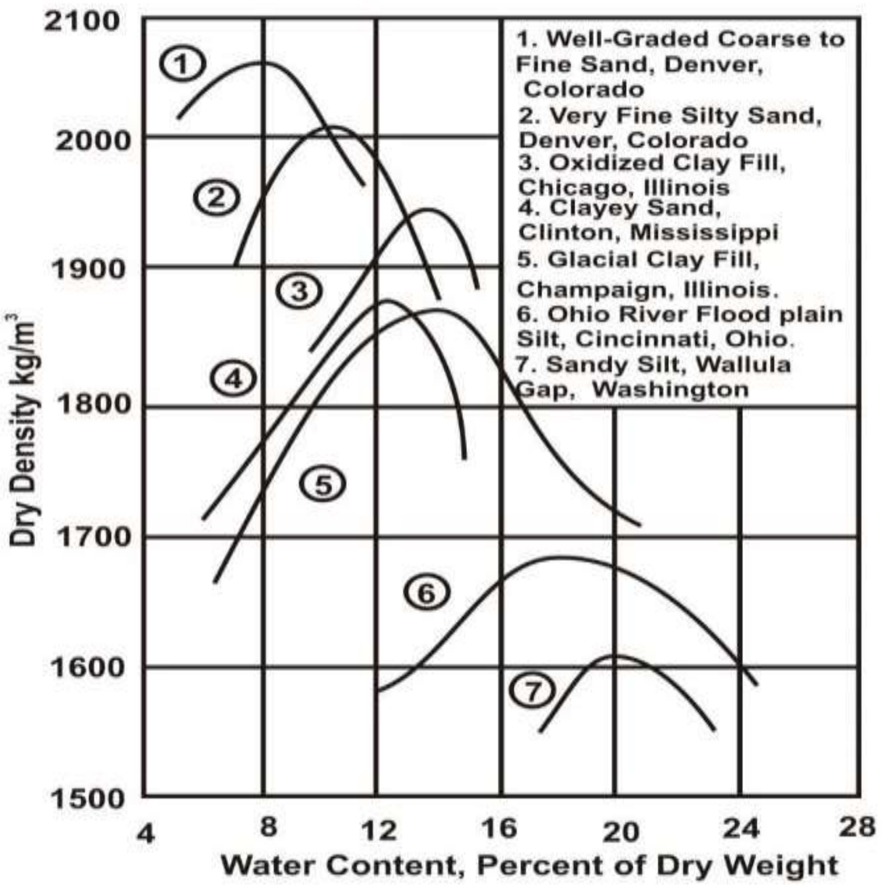
Shallow Densification



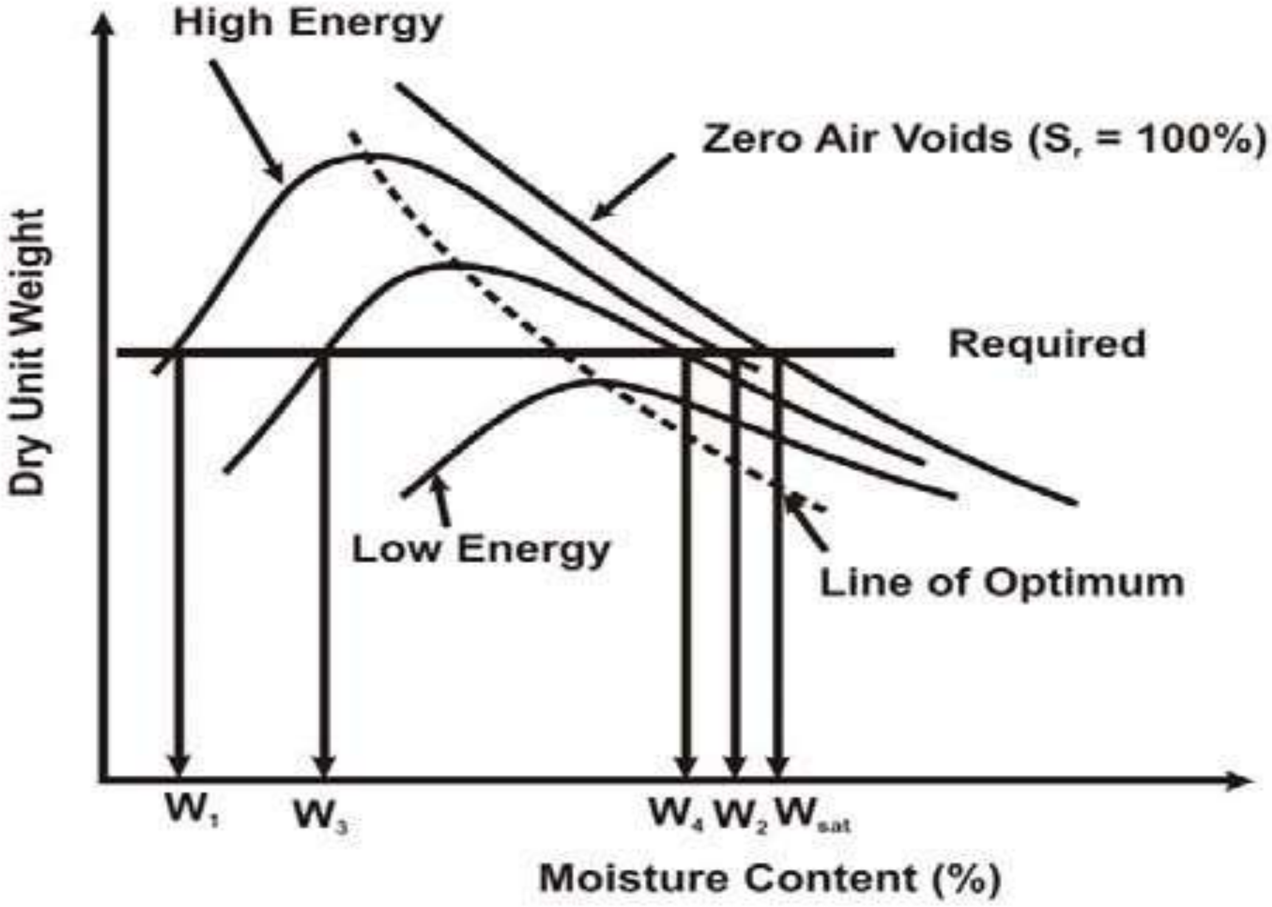
Shallow Densification: Effect of Compactive Effort



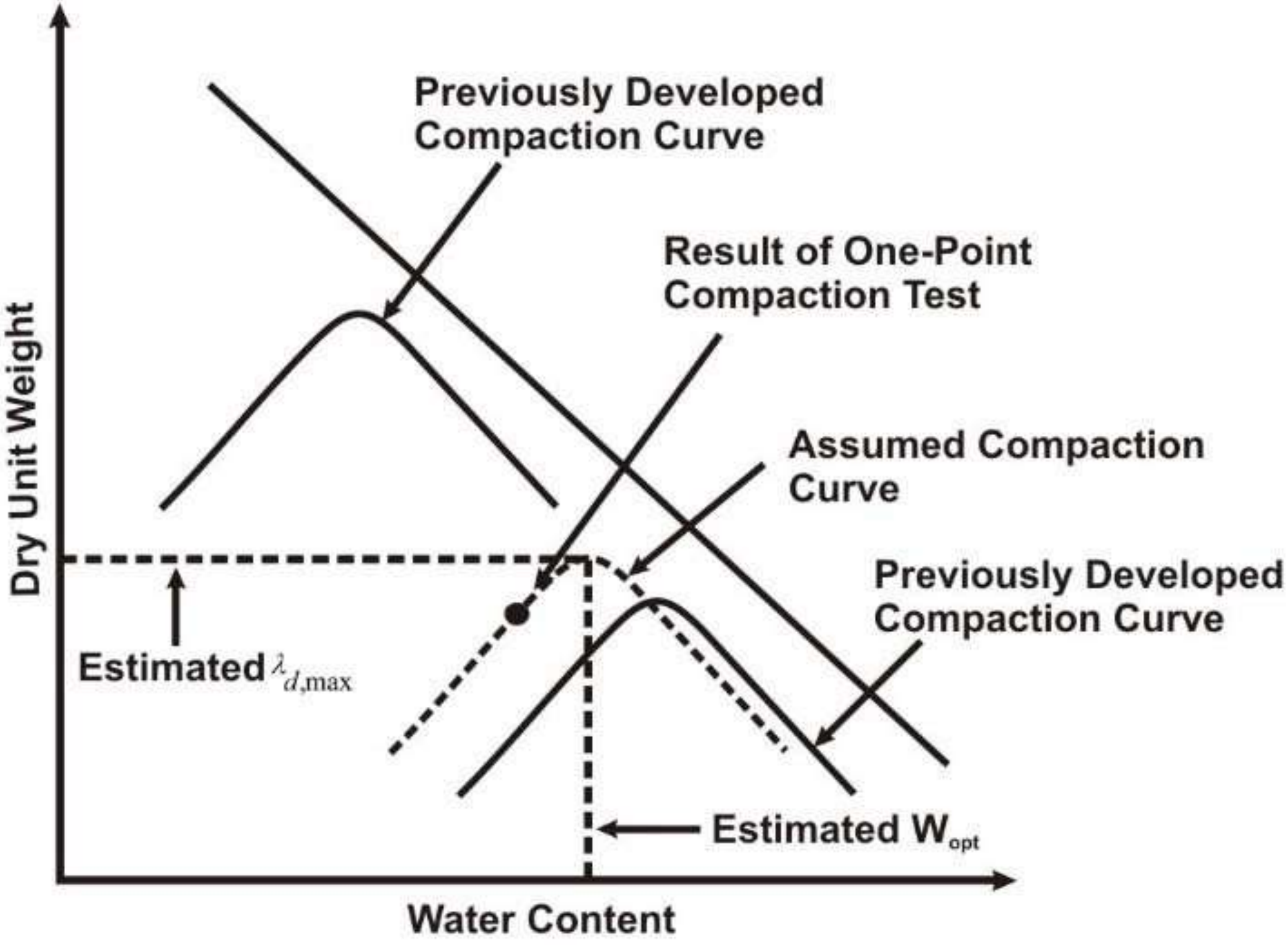
Shallow Densification: effect of Geomaterials



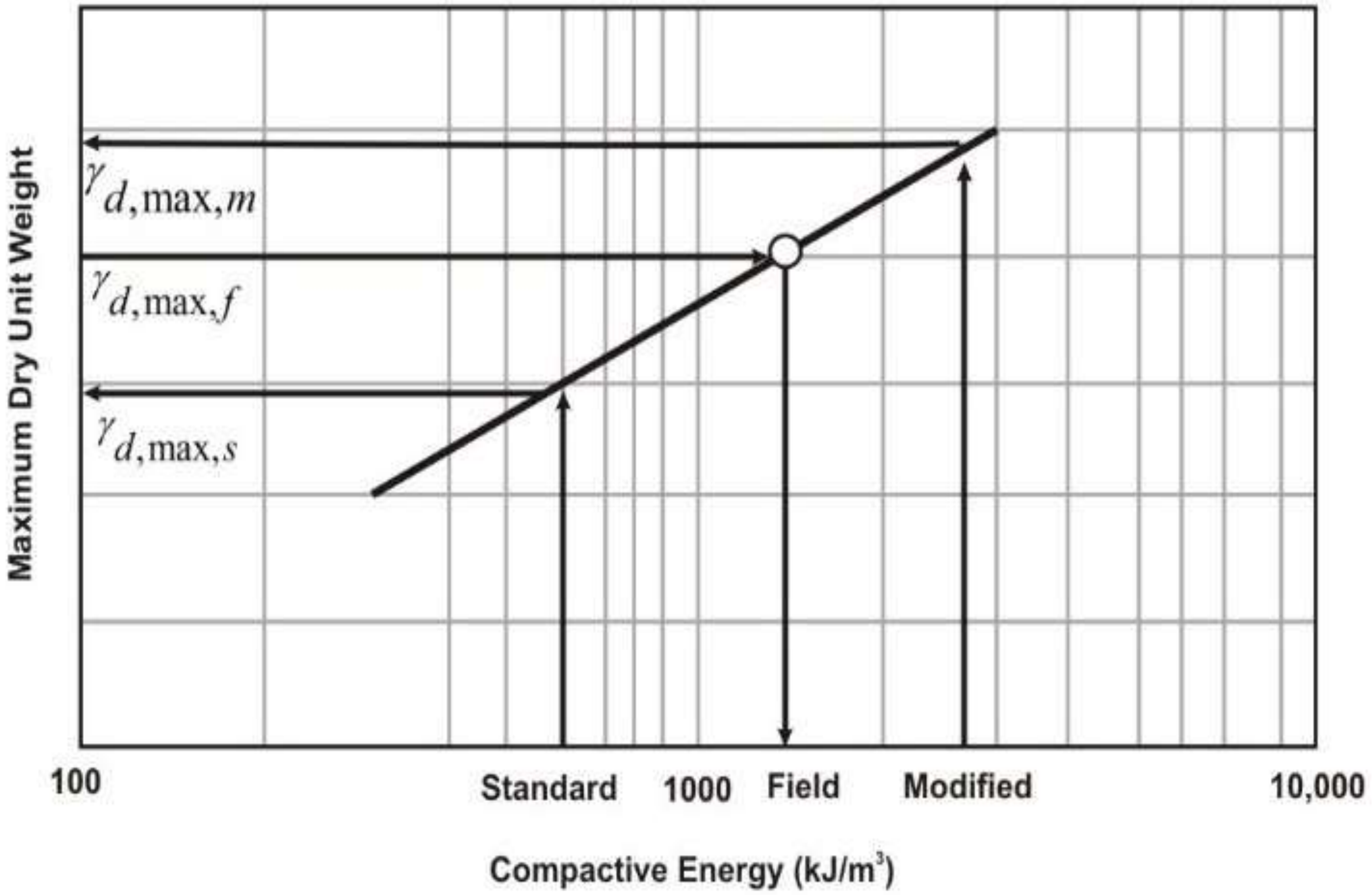
Range of water content For Effective compaction



Prediction of OMC and MDD for an intermediate compactive effort from previously developed compaction Curve



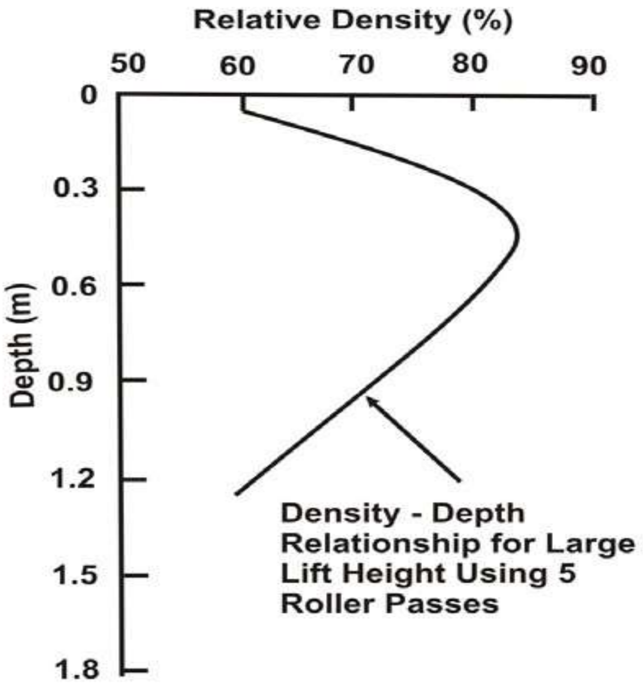
Applied Energy versus MDD



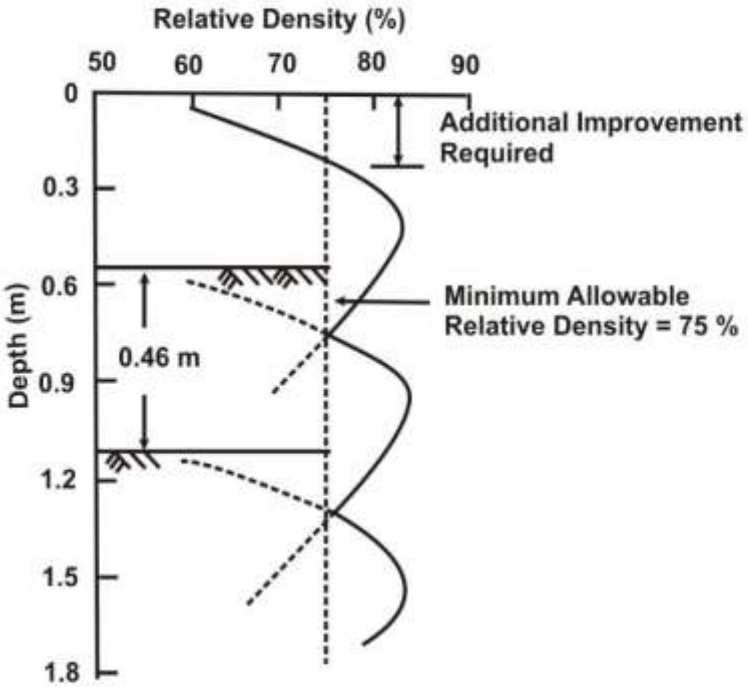
Influencing Factors for relative compaction:

- Type of Geo-materials
- Moisture content
- Compaction method
- Compaction effort including applied energy, compactor size, lift thickness, and number of passes
- Relative layer stiffness

Density Achieved over depth

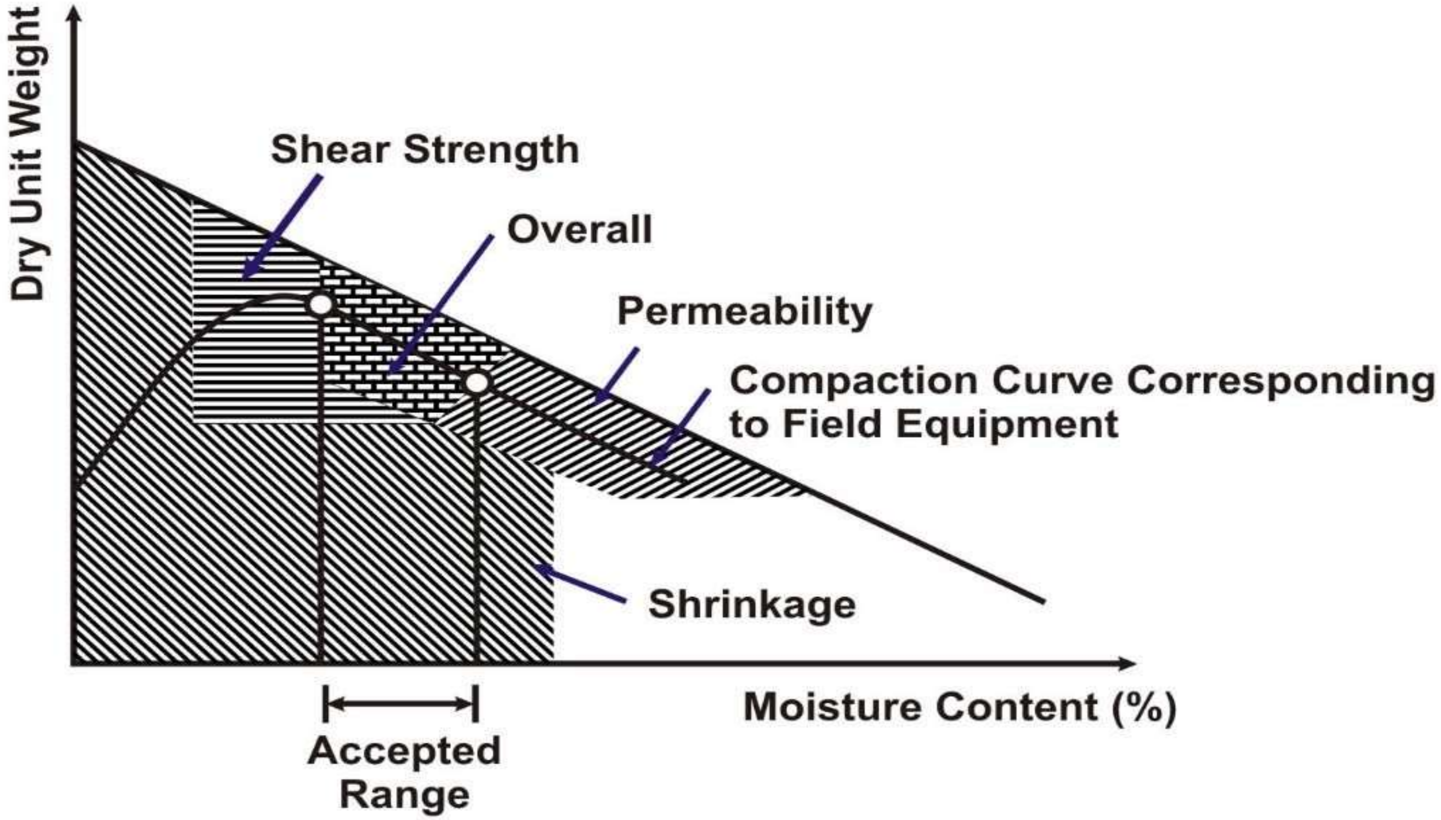


(a)



(b)

Acceptable range of water content for different objectives



Recommended Relative compaction for different work

Compaction fill for	% of Modified Maximum dry unit	Moisture range about optimum moisture content
Roads D = 0 – 0.5 m	90-105	-2 to +2
Roads D>0.5 m	90 – 95	-2 to +2
Small Earth Dam	90 - 95	-1 to + 3
Large Dam	95	-1 to +2
Embankment	95	-2 to +2
Foundation	95	-2 to +2
wall	90	-2 to +2
Trench	90	-2 to +2
Clay liner	90	0 to +4

Recommended equipment for different Geomaterials

Geo-material Type	First Choice	Second Choice	Comments
Rock Fill	Vibratory Roller	Rubber Tire Roller	
Plastic Soil, CH, MH	Sheep foot roller	Rubber tire roller	Thin lifts desired
Law plasticity soil-CL, ML	Sheep Foot Roller	Rubber tire vibratory roller	Moisture control is critical
Plastic sands and gravels-GC, SC	Vibratory, Pneumatic roller	Pad food roller	
Silty sands and gravels-SM GM	Vibratory roller	Rubber tire, pad foot roller	Moisture control critical
Clean sand-SW, SP	Vibratory roller	Impact, rubber tire roller	
Clean gravels-GW, GP	Vibratory roller	Rubber tire, impact, grid roller	Grid useful for over sized particles

Recommended lift thickness and No. of passes for different eqipment

Equipment	Applicability	Compacted lift thickness	Number of Passes
Sheep foot roller	For fine grained fills or coarse grained fills with more than 20% fines	150 mm	4-6 for fine grained fills 6-8 for coarse grained fills
Rubber tire roller	For clean coarse grained fills with 4 - 8% fines	250 mm	3-5
	For fine grained fills or well graded coarse grained fills with more than 8% fines	150-200	4-6
Smooth wheel roller	Appropriate for sub-grade or base course compaction of well graded sand gravel mixtures	200-300	4
	May be used for fine grained fills other than earth dams	150-200	6

Recommended lift thickness and No. of passes for different equipment

Equipment type	Applicability	Compacted lift thickness	Number passes
Vibrating smooth drum rollers	For coarse grained fills and sand gravel mixtures-rock fill	200-300 mm for soil 900 for rock	4-6
Vibrating plate compactors	For coarse grained fills with less than 4-8% fines, placed thoroughly wet	200-250	3-4
Crawler tractor	Best suited for coarse grained fills with less than 4-8% fines placed thoroughly wet	150-250	3-4
Power tamper or rammer	For difficult access, trench backfill, suitable for all inorganic fills	100-150 for silt or clay, 150 for coarse grained fills	2

PROBLEM

The in-situ moisture content of a soil at a borrow area is 14% and its moist unit weight is 17.0 kN/m^3. The specific gravity of solids for the soil is 2.70. The soil is to be excavated and transported to a construction site for use in a compacted fill. The finished compacted volume is 2000 m^3. If the specifications call for the soil to be compacted to a dry unit weight of 18.0 kN/m^3 at the moisture content of 16% (assume unit weight of water = 9.81 kN/m^3)

(i) What is the void ratio of the compacted soil? (ii)What is the degree of saturation of soil after compaction? (iii) What is the volume of soil (in cubic meter) to be borrowed from the borrow site? (iv) If a dump truck can carry 150 kN of soil in a trip, what will be the number of trips required to transport the soil to the construction site? (v) What is the amount of water (in kN) to be added to the borrow soil to give desired compaction?

The following data refers to a light compaction test as per Indian Standard:

Water content(%)	8.5	12.2	13.75	15.5	18.2	20.2
Wt of wet sample(kg)	1.80	1.94	2.00	2.05	2.03	1.98

If the specific gravity of soil grains was 2.7 (i) Plot the compaction curve and obtain the maximum dry unit weight and the optimum moisture content (ii) plot the 80 % and 100% saturation lines (iii) if it is proposed to secure a relative compaction of 95% in the field, what is the range of water content that can be allowed? (iv) would the 20 % air voids curve be the same as the 80% saturation curve?

IS mould volume = 1000 cc

$$\gamma_d = \frac{\gamma_{bulk}}{(1+w)}$$

Water content	8.5	12.20	13.75	15.50	18.20	20.20
Dry unit weight, (kN/m^3)	16.26	16.94	17.23	17.39	16.83	16.14
for S = 80% (kN/m^3)	20.56	18.74	18.07	17.37	16.39	15.73
for S = 100% (kN/m^3)	21.52	19.89	19.30	18.65	17.74	17.12

$$\gamma_d = \frac{G_s \gamma_w}{1 + (wG_s/S)}$$

GROUND IMPROVEMENT

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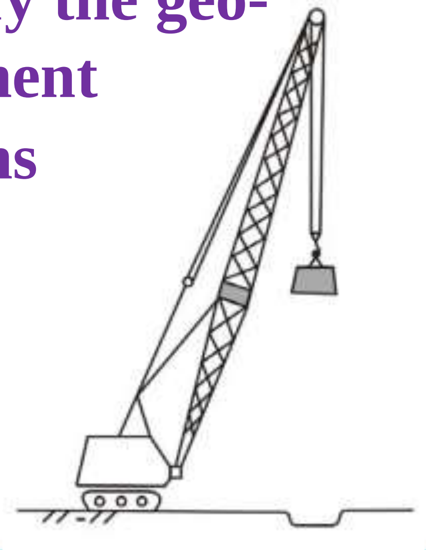
Deep Dynamic Compaction

Advantages, Disadvantages and Area of Application

Basic Concepts:

- Repeated drop of weight freely from a height on to the ground surface
- Use a definite pattern to cover the ground to be improved
- Repeated impacts reduce voids, densify the geo-material, and induce ground improvement
- A tamper typically has weight 5-10 tons
- Drop height 10-40 m
- Compact up to a depth of 10 m



Suitability

- Loose and partially saturated fills
- Saturated free drained soils
- Silts with plasticity index less than 8
- Clayey soil with low degree of saturation (moisture content lower than plastic limit)

▪Deep dynamic compaction is generally not recommended for clayey soils with high plasticity index and high degree of saturation

▪Drainage and dewatering are required to reduce excess pore water pressure in clayey soil generated by deep dynamic compaction if used for such soils

▪High water table reduces the effectiveness of dynamic compaction

Adverse situations for dynamic compaction

Adverse Situation	Possible difficulty
Soft Clays (cu<30 kPa)	Insufficient resistance to transmit tamper Impulse
High Ground water level	Need dewatering
Vibration effects	Distance from the closest structure to be in the order of 30 m or more
Clay surface	May be inadequate for heavy cranes
Clay fills	May be subjected to collapse settlement if inundated later
Flying debris	Requires precautions for site and public safety
Voided Ground or Karst feature below the ground	Treatment may not reach the voided zone or make it less stable
Biologically degrading material	Compaction may create anaerobic condition and regenerate or change the seat of biological degradation

Application: Used to improve problematic geomaterials by increasing bearing capacity, reducing settlement, minimizing collapsible potential and mitigating liquefaction potential for commercial and residential buildings, storage tanks, highways and railways, airports, and harbors

Advantages:

- Improve a large area of geo-materials in a relatively short time at low cost
- Effective for loose and partially saturated fill with less than 15 % fines
- Can detect weak or loose areas during operation
- Can change a heterogeneous material to a more uniform, denser, and stronger material
- Major equipment needed for this method is a crane and tamper which are readily available

Disadvantages:

- ❑Generally less to not effective to improve saturated clayey soils
- ❑Drainage and dewatering and long waiting period is required to use for saturated clay soils
- ❑Induce noise, vibration and lateral movement which may cause problems to nearby buildings, substructure and utility lines
- ❑Mobilization cost may be high when large crane and tamper are used
- ❑Required instrumentation to monitor various aspects

Dynamic Densification:

When dynamic Compaction is used on unsaturated granular geo-material, the impact by a heavy tamper immediately displaces particles to a denser state, compresses or expels air out of voids, and reduces the volume of voids

Dynamic Consolidation:

- **Compressibility of Saturated soils (1 to 4%)**
- **Generation and dissipation excess pore water pressure**
- **Change of permeability**
- **Thixotropic recovery**

Compressibility of Saturated soils (1 to 4%): Saturated fine grained soil is incompressible and can not have volume change under immediate loading (undrained condition). Menard and Broise (1975) attributed the immediate volume change of saturated fine-grained soil to the existence of microbubbles in most quaternary soils ranging from 1 to 4%

Generation and dissipation excess pore water pressure:

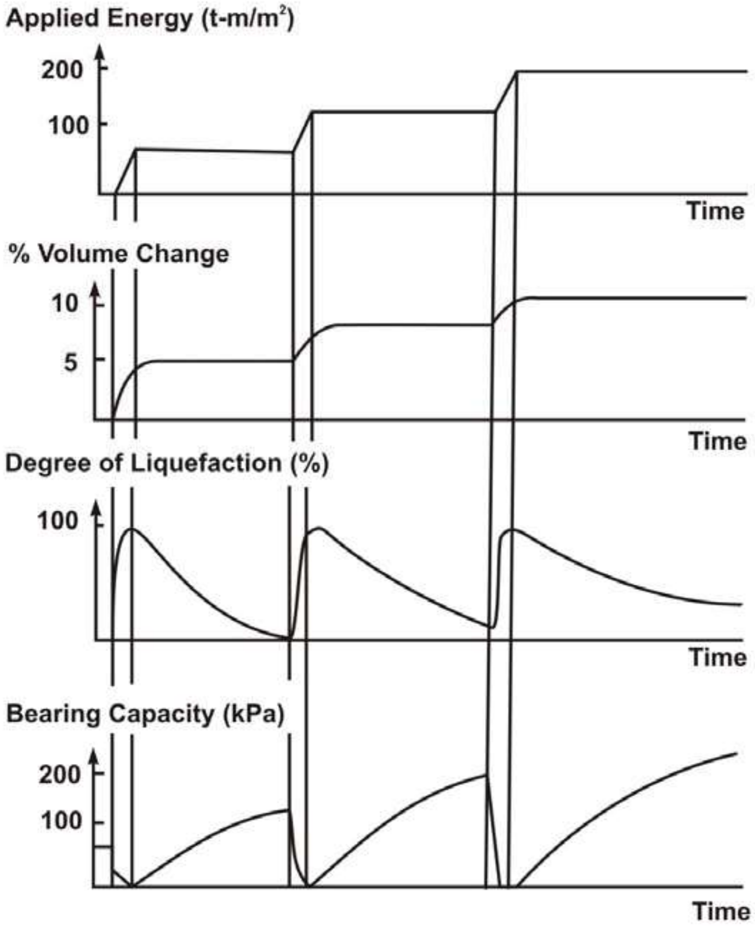
Dynamic compaction induces excess pore water pressure during the operation. A waiting period is necessary to dissipate the excess pore water pressure. The dissipation of excess pore water pressure is a consolidation process, which can induce settlement and compress the soil. Due to the low permeability of fine-grained soils, prefabricated vertical drains are often installed to accelerate the dissipation

Change of permeability: Under high-energy tamping, vertical fissures are generated around the impact points. These vertical fissures significantly increase the permeability of the fine- grained soil, which also accelerates the dissipation of excess pore water pressure and consolidation

Thixotropic recovery:

Due to the disturbance of finegrained soil caused by tamping, it degrades and reduces its strength. This strength regains with time due to the thixotropic recovery. This is also the reason why fine-grained soils should be evaluated at least 30 days after tamping

Illustration of changes of volume, excess pore water pressure, and soil strength during and after tamping

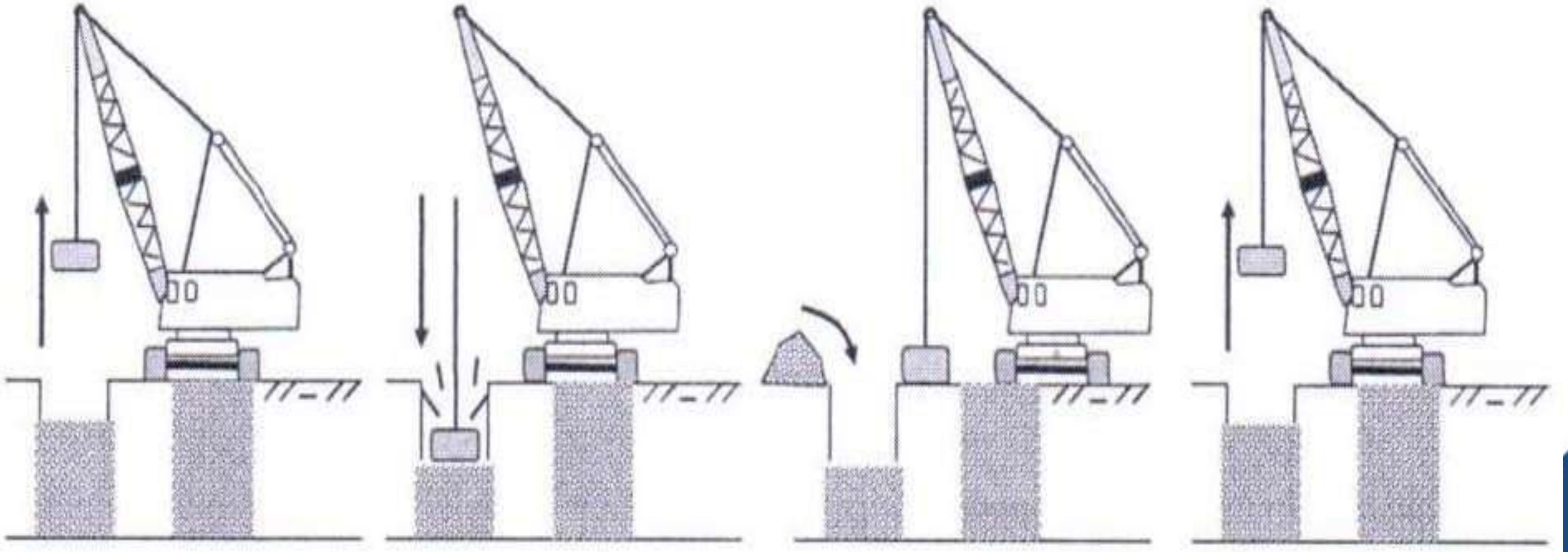


Dynamic Replacement:

- Too soft Clayey soils with too low permeability densification or consolidation is ineffective during and after tamping

- Instead of improving the soil the soil is displaced by tamping and replaced by stones or coarse aggregates

- Involves tamping, backfilling and continued tamping until stone columns are formed



GROUND IMPROVEMENT

Deep Dynamic Compaction
Design Steps

Dynamic Replacement:

- **Too soft Clayey soils with too low permeability densification or consolidation is ineffective during and after tamping**

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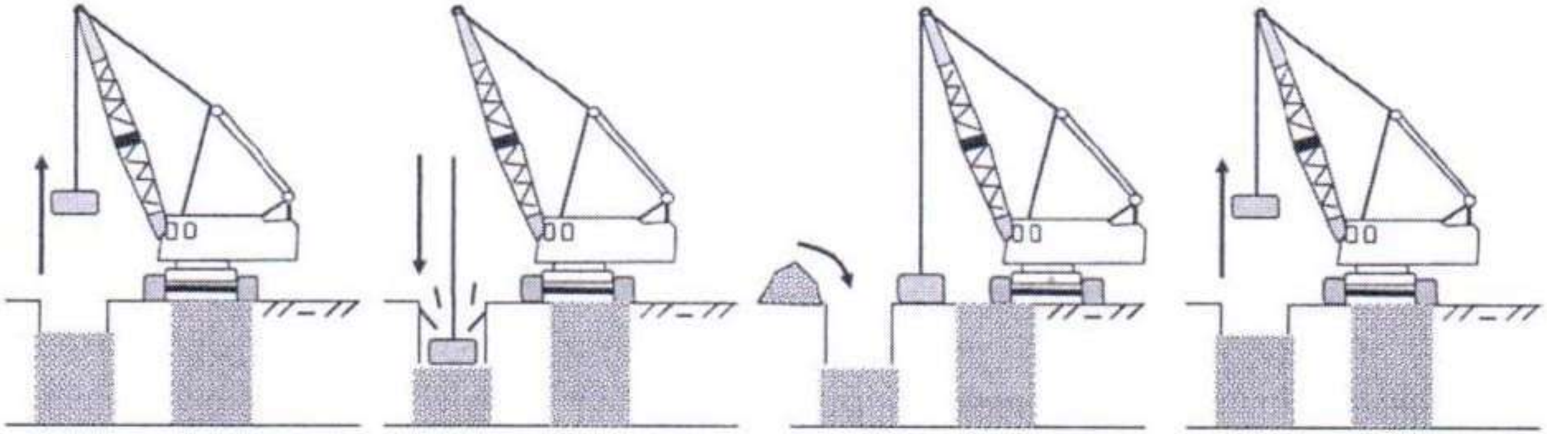


Design Consideration: **Before the design of deep compaction a geotechnical investigation is required to evaluate the site conditions which includes:**

- **Geotechnical profiles including geo-material type, particle size, fine content, degree of saturation and Atterberg's limits**
- **Relative density of cohesionless geo-material**
- **Ground water level**
- **Possible voids**
- **Possible presence of hard lenses within the depth of improvement**
- **Possible sensitive soil**

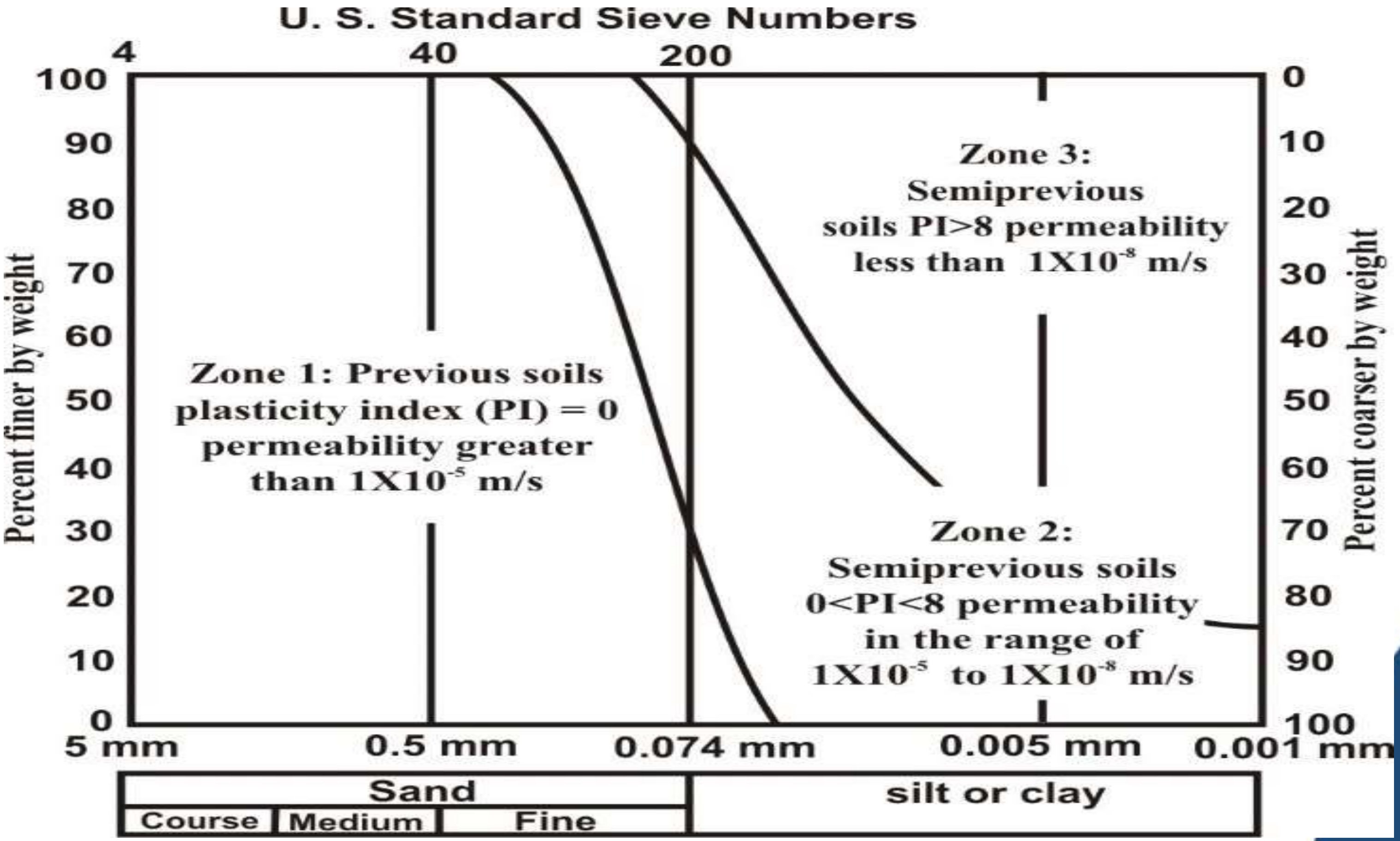
Influence Factors

The design of deep dynamic compaction should consider the following influence factors:

- ❑ **Geo-material type**
- ❑ **Depth and area of improvement**
- ❑ **Tamper geometry and weight**
- ❑ **Drop height and energy**
- ❑ **Pattern and spacing of drops**
- ❑ **Depth of crater**
- ❑ **Number of drops and passes**
- ❑ **Degree of improvement**
- ❑ **Induced settlement**
- ❑ **Environmental impact (vibration, noise and lateral ground movement)**
- ❑ **Presence of soft layer**
- ❑ **Presence of Hard layer**
- ❑ **High ground water table**
- ❑ **Elapsed time**
- ❑ **Pilot trial**

Three types of soil that are suitable for dynamic compaction:

(1) Previous soil deposits—granular soil,
(2) Semi-pervious deposit—primary silts with plasticity index less than 8,
(3)Semi=pervious deposit—primary clayey soil with plasticity index greater than 8.


U. S. Standard Sieve Numbers
4
40
200
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Percent finer by weight
Percent coarser by weight
Zone 1: Previous soils
plasticity index (PI) = 0
permeability greater
than 1X10⁻⁵ m/s
Zone 3:
Semiprevious
soils PI>8 permeability
less than 1X10⁻⁸ m/s
Zone 2:
Semiprevious soils
0<PI<8 permeability
in the range of
1X10⁻⁵ to 1X10⁻⁸ m/s
5 mm
0.5 mm
0.074 mm
0.005 mm
0.001 mm
Sand
silt or clay
Course
Medium
Fine

Depth and area of Improvement:

Depth of improvement depends on project requirements for desired performance For example, a loose and saturated sand layer susceptible to liquefaction, should be improved to the depth below which no liquefaction will occur. An empirical formula developed based on field data:

$$D_i = n_c\sqrt{W_t H_d}$$

***Di* = depth of improvement in m, *Wt* = weight of tamper (ton),**
***Hd* = height of drop in m, *nc* = constant**

The formula is units dependent. The specific units as noted in the definitions should be used.

Depth of improvement in different soils Sand up to 10 m
Cohesive soils and clay fill up to 5 m

The area of the improvement should be that beyond the area of loading with a distance equal to the depth of improvement on each side.

nc values for different types of soil

Type of soil	Degree of Saturation	*nc*
Pervious soil deposits – Granular soil	High	0.5
	low	0.5-0.6
Semi-pervious deposits – Primary silts with PI≤8	High	0.35-0.4
	Low	0.4-0.5
Semi-pervious deposits – primary clayey soils with PI>8	High	NR
	Low (w<PI)	0.35-0.4

Tamper geometry and weight:

- Made of steel or steel shell infilled with sand or concrete
- Circular or square base with area 3-6 sq m or more
- Tamper with smaller base area (3 – 4 sq m) are commonly used for granular soils
- Large areas (more than 6 sq-m) are used for cohesive soils
- Weight typically 5 to 40 tons

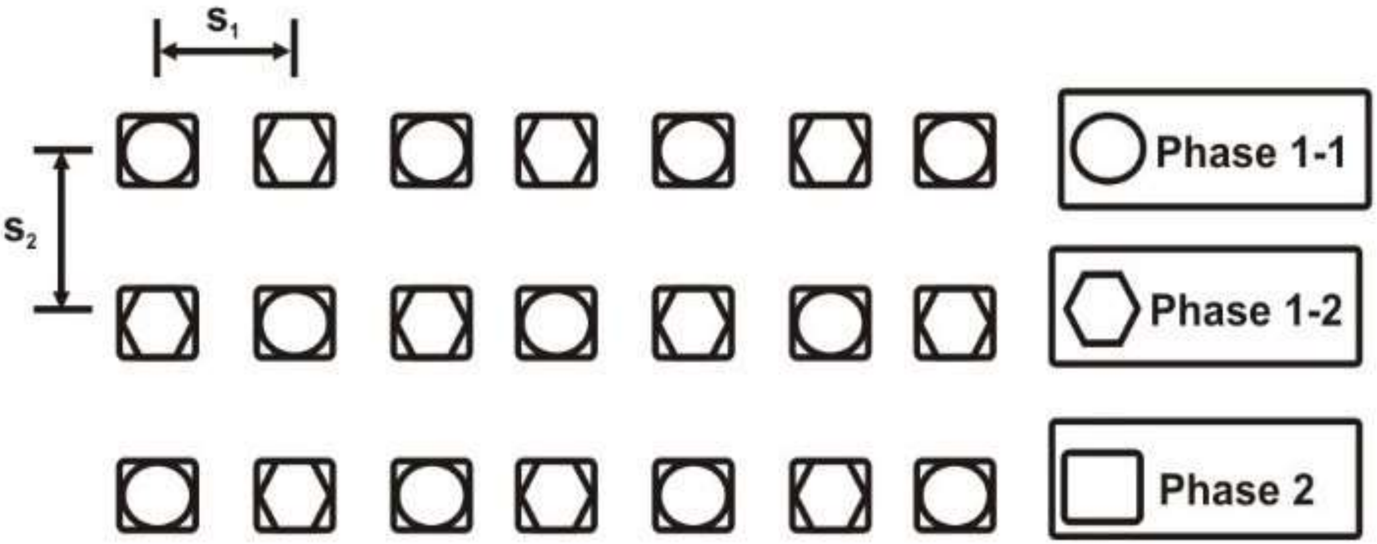
Height of Drop and Energy

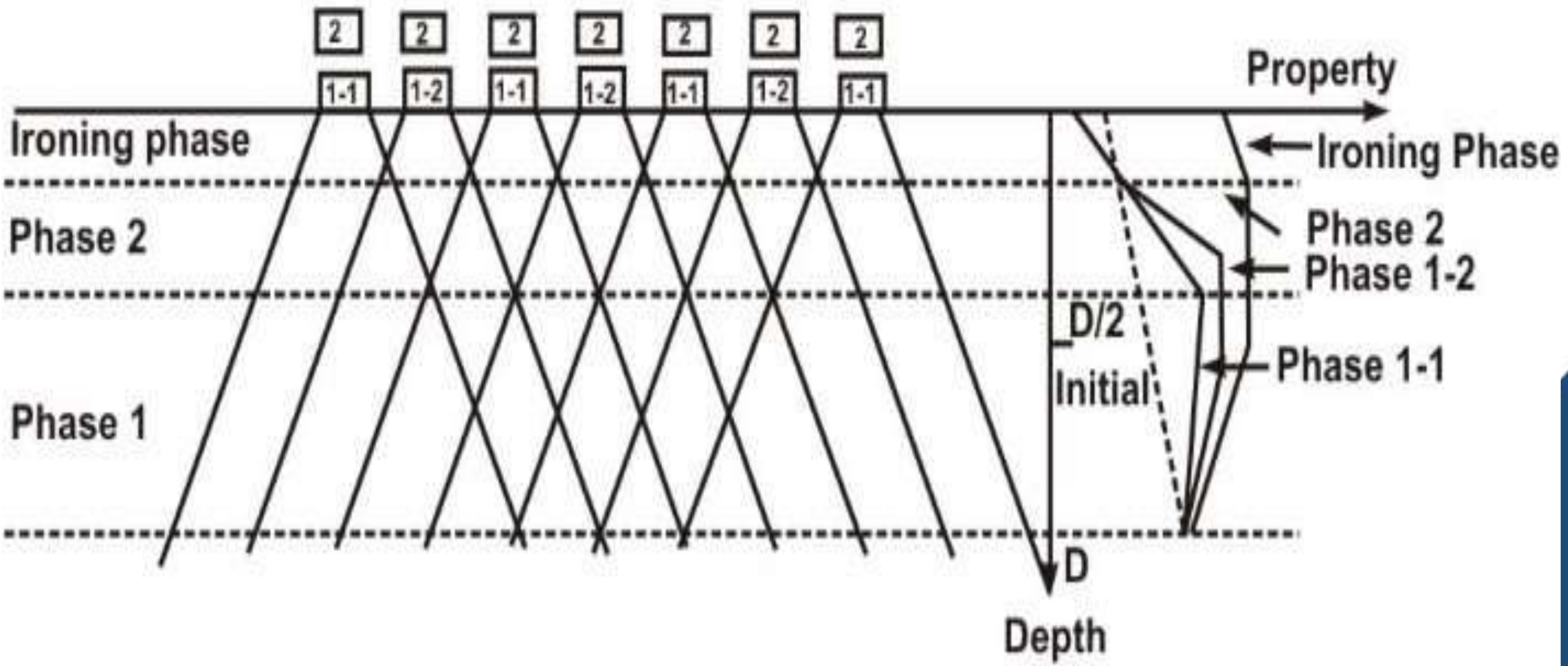
The height of tamper drop is typically 10–40 m. The energy per drop in practice ranges from 800 to 8000 kN-m. Mayne et al. (1984) provided a chart of relationship between weigh of tamper and drop height based on field data. The relationship can be approximately expressed as given below:

$$H_{\mathrm{d}} = (W_{\mathrm{t}} H_{\mathrm{d}})^{0.54}$$

The calculated drop height may be adjusted based on the available tamper owned by the contractor.

Pattern and spacing




2
2
2
2
2
2
2
1-1
1-2
1-1
1-2
1-1
1-2
1-1
Property
Ironing phase
Phase 2
Phase 1
Ironing Phase
Phase 2
Phase 1-2
D/2
Initial
Phase 1-1
D
Depth

Depth of Crater: **A crater is formed under each tamper drop and its depth increases with the number of passes. High energy compaction can induce a crater of 1.0 – 1.5 m deep. Crater depth should be *ht* of tamper plus 0.3 m to ensure safety and ease of compaction operation**

$$d_{cd} = 0.28\, N_d^{\,0.54} \sqrt{W_t\, H_d}$$

$$log d_{\mathrm{cd}} = -1.42 + 0.533 log N_{\mathrm{d}} + 0.213 log H_{\mathrm{d}} + 0.873 log W_{\mathrm{t}} - 0.435 log \left(\frac{s_{\mathrm{d}}}{d_{\mathrm{t}}}\right) - 0.118 \log p$$

dcd **= craterd epth,** ***Hd*** **= drop height m,** ***Wt*** **= tamper weight in ton,** ***Nd*** **= number of drops,** ***sd*** **= spacing of drops,** ***dt*** **= tamper width or diameter,** ***p*** **= contact pressure in t/m2**

Dynamic compaction on soil with a high degree of saturation would result in deeper crater depth

Number of Drops and Passes: **The number of drops and passes can be estimated based on applied energy on site**

$$AE = \frac{N_d W_t H_d}{A_e}$$

Applied energy at each drop point location can be calculated based on the equation above

Where *Nd, Wt,* and *Hd* as defined before, and *Ae* is equivalent influence area in each impact point

$$A_e = s^2 \ for\ square\ pattern$$

$$A_e = 0.867\ s^2 \ for\ triangular\ pattern$$

Total applied energy is the sum of the energy applied during high energy passes plus ironing pass. Unit applied energy is defined based on the depth of improvement as follows:

$$UAE = \frac{AE_{total}}{D_i} = \frac{AE_{HEP}N_p + AE_{IP}}{D_i}$$

Ironing pass is mainly used to compact loosened soil within the depth of craters. The required applied energy for ironing compaction is estimated as follows:

$$AE_{IP} = UAE.d_{cd}$$

Required Unit Applied Energy, UAE

Soil type	Unit applied Energy(KJ/m3)	% of standard proctor energy
Pervious coarse grained soil	200-250	33-41
Semi impervious fine grained soil	250-350	41-60
Landfill	600-1100	100-180

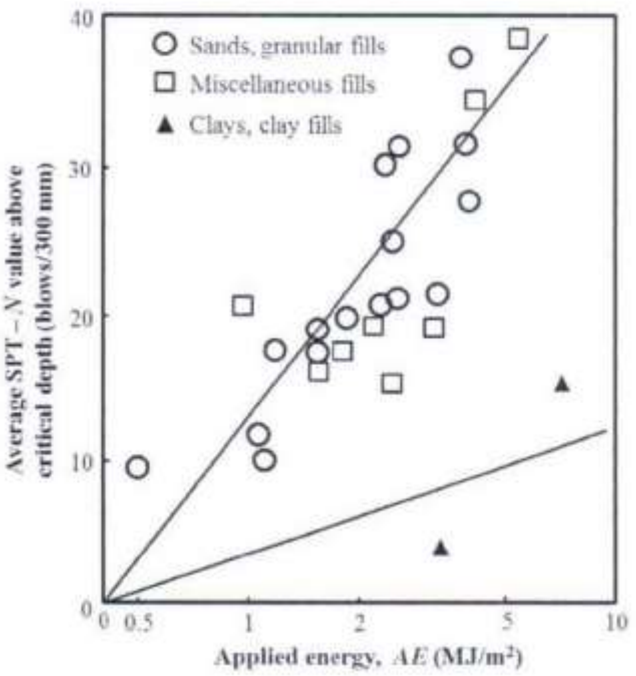
The number of drops can be determined through trial tamping work onsite. The Chinese *Ground Improvement Technical Code* (China Academy of Building Research, 2000) sets the following criteria to determine the number of drops from trial tamping work

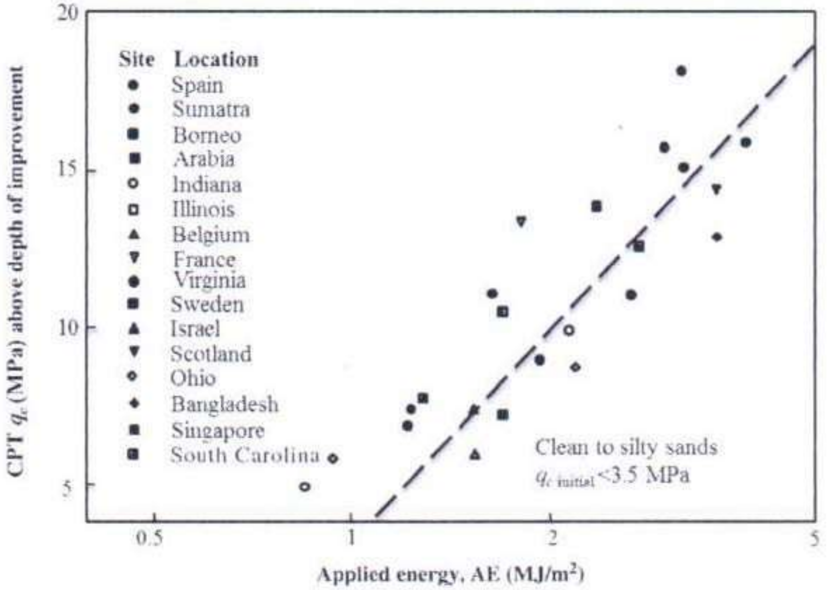
- The average vertical displacement induced by the last two drops is not greater than 50 mm. When high drop energy is used, it should not be greater than 100 mm.
- No large heave occurs around the crater.
- The crater should not be so deep that lifting of the tamper becomes difficult

Degree of Improvement: The degree of improvement depends on

- Geomaterial type
- Fine content
- Groundwater table
- Applied energy
- Drop layout
- Time

Two Figures show the average SPT *N* values, CPT tip resistance above the improvement depth. Table provides upper bound test values after dynamic compaction. These figures and table can be used as target values for dynamic compaction preliminary design. The actual degree of improvement should be evaluated by in situ testing after compaction


○ Sands, granular fills
□ Miscellaneous fills
▲ Clays, clay fills
Average SPT – N value above critical depth (blows/300 mm)
0
10
20
30
40
0
0.5
1
2
5
10
Applied energy, AE (MJ/m²)


Site Location
● Spain
● Sumatra
■ Borneo
■ Arabia
○ Indiana
□ Illinois
▲ Belgium
▼ France
● Virginia
■ Sweden
▲ Israel
▼ Scotland
◇ Ohio
◆ Bangladesh
■ Singapore
■ South Carolina
Clean to silty sands
$q_{c\ initial}$ <3.5 MPa
CPT q_c (MPa) above depth of improvement
5
10
15
20
0.5
1
2
5
Applied energy, AE (MJ/m²)

Upper Bound Test Values after Dynamic Compaction

Soil type	SPT N value	CPT MPa	PMT
Pervious coarse grained soil: Sands and Gravel	40-50	19-29	1.9-2.4
Semi-impervious soils			
Sands and Gravel	40-50	19-29	1.9-2.4
Silts and clayey silts	25-35	10-13	1.0-1.4
Partially saturated impervious deposits			
Clay fills and mine spoil	30-40	NA	1.4-1.9
Landfills	20-40	NA	0.5-1.0

Induced settlement: After each pass of dynamic compaction usually bulldozers are used to level the ground surface. Ground settlement is measured based on current ground elevation as compared to the original ground elevation. In unsaturated soil settlement occurs immediately after compaction. In saturated soil, settlement increases gradually with time after the initial compression under each compaction.

Approximate Induced Settlement as Percent of Improvement Depth

Soil type	Percent of depth
Natural clays	1-3
Clay fills	3-5
Natural sands	3-10
Granular fills	5-15
Uncontrolled fills	5-20

Environmental Impact: It is expected that applying high-energy impact on ground induces environmental impact, mostly vibration, noise and lateral movement. This fact has to be considered in the selection of a suitable ground improvement technique. A loose soil or fill typically generate lower peak particle velocity. Peak particle velocity is the measure of disturbance. Lukas (1995) indicated that the frequency of ground vibration induced by dynamic compaction ranges between 6 and 10 Hz

$$PPV = 70\left(\frac{\sqrt{W_{\mathrm{t}}H_{\mathrm{d}}}}{x_{\mathrm{dp}}}\right)^{1.4}$$

xdp is the distance from the drop point

Typical Threshold Particle Velocity

Structure Type	Velocity(mm/s)
Commercial, industrial	20-40
Residential	5-15
Sensitive	3-5

THANK
YOU

GROUND IMPROVEMENT

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Module 03: Deep Dynamic Compaction

Lecture 14 : Construction, quality control and assurance

Design Parameters: Influence factors discussed before are the design parameters and once again shown in the table below

- Geo-material type
- Depth and area of improvement
- Tamper geometry and weight
- Drop height and energy
- Pattern and spacing of drops
- Depth of crater
- Number of drops and passes
- Degree of improvement
- Induced settlement
- Environmental impact (vibration, noise and lateral ground movement)
- Presence of soft layer
- Presence of Hard layer
- High ground water table
- Elapsed time
- Pilot trial

Procedure: Procedure for deep dynamic compaction is presented below

1. Based on geotechnical profile and potential problem, select the depth of improvement.
2. Based on geomaterial type and degree of saturation, select the *nc* value from Table in lecture 12
3.Calculate the required energy per blow for the high-energy impact using Equation in lecture 13 based on the required depth of improvement.
4. Estimate the drop height using Equation from lecture 13 and then the tamper weight.
5.Based on the applied energy guidelines, the unit applied energy can be selected based on the geomaterial type using Table from lecture 13.

6. Calculate the required total applied energy using Equation from lecture 13
7.Based on the geomaterial type and degree of saturation near the ground surface, the required unit applied energy for the ironing pass can be selected using Table in Lecture 13.

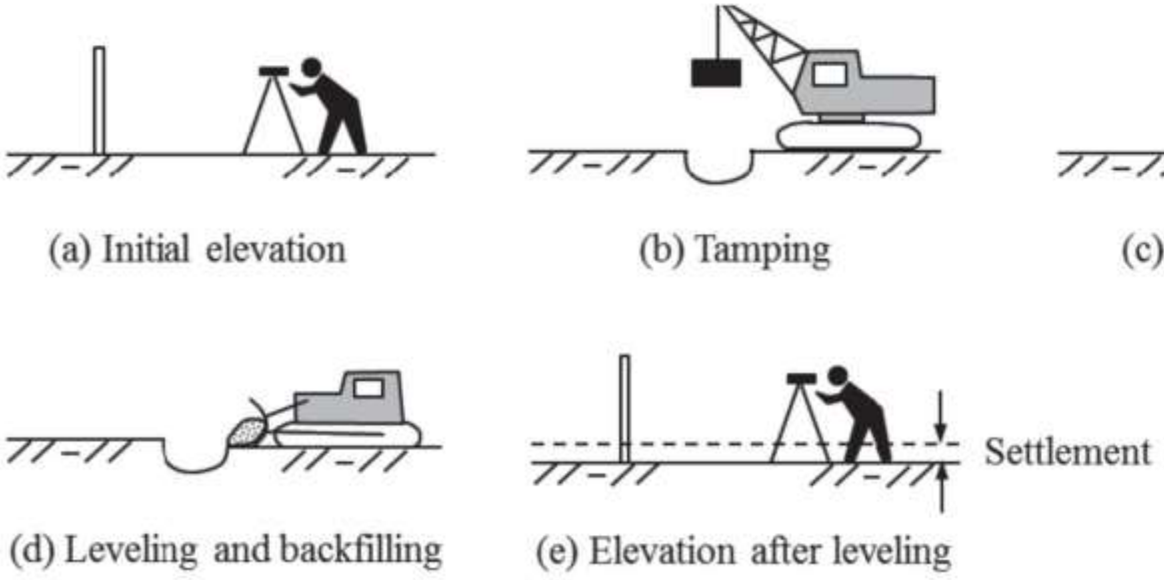
8.Calculate the required applied energy for the ironing pass using Equation in lecture 13 with an assumed crater depth (typically 1.0–1.5 m).
9.Calculate the required total applied energy for high-energy compaction by subtracting the required applied energy for the ironing pass from the total required applied energy.
10. Based on the tamper diameter, estimate the spacing of drops.
11.Based on the required total applied energy for high-energy compaction and the spacing of drops, calculate the required number of drops (round up to an integer number). If the required number of drops on one location is greater than 10, multiple passes or phases are required.
12. Estimate the crater depth using Equation in lecture 13
13. Select target performance values after improvement.
14.Estimate the settlement after improvement based on Table in lecture 13 or crater depth.

Construction : Before construction, the equipment used for lifting and dropping a tamper should be selected based on the weight of the tamper. FHWA (1986) provided a guideline for the selection of equipment for different tamper weights as shown in the Table below

Tamper Weight (kN)	Crawler Crane Capacity (kN)	Cable size (mm)
50 -70	360 - 440	19 -22
70 -130	440 - 890	22 -25
130 - 160	890 - 1100	25 - 29
160 - 220	1300 - 1600	32 - 38

A conventional crawler crane with a single cable and a free spool is typically sufficient for a tamper weighing up to 220 kN. For heavier tampers, the crawler crane should be reinforced with stronger components.

A typical flow of tamping work is shown in the Figure below:



In any tamping work steps are as detailed below:

1. Prepare a site by removing large objects (e.g., trees), leveling the ground, dewatering, and filling existing ponds and local depressed area. If the groundwater is within 2 m from the ground surface, it should be lowered by dewatering or additional fill is placed. If the surface soil is too weak to support equipment, a construction platform should be constructed first.

2.If there are nearby existing structures or utility lines, an isolation trench is required to minimize vibration and lateral movement. Trench should be at least 2–3 m deep and 1 m wide at the bottom of the trench.

3.Place stakes at the locations for the centers of all the drop points for each pass and survey the ground elevations.

4. Position the equipment and move the tamper right above the drop point

5. Survey the top elevation of the tamper on the ground

6.Lift the tamper to the desired height and then let it drop freely onto the ground. Survey the top elevation while the tamper is still in the crater. Alternatively, measure the dimensions of the crater after removing the tamper. If the tamper is tilted after reaching the ground, level the base of the crater after removing the tamper

7.Repeat step 6 until the number of drops on one tamping point reaches the target value and other criteria are met. Move to the next tamping point

8. Repeat steps 4–7 until all the tamping points are complete for the first pass.

9. Use bulldozers to level the ground and measure the ground elevation. The difference between the current elevation and the previous elevation is the induced settlement.

10. After an elapsed time depending on geomaterial and groundwater conditions, repeat steps 3–8 until all the tamping points are complete for the next passes if needed.

11. Apply ironing tamping over the whole compaction area

Quality Control and Assurance

- The height of drop and locations of drop points should be verified before tamping work
- Need monitoring and close visual observations and adjustments if needed may be made based on monitoring and observations.
- For example, if one drop location has a much deeper crater depth than other locations, this is an indication that much weaker geomaterial exists at that location. Special measures may be necessary to improve this area, such as overexcavation and replacement. If additional tamping induces large heave around the crater, this is an indication that further densification is not effective so that the tamping should be suspended or terminated at this location.

- Other field monitoring techniques used include Piezometer for saturated fine-grained geomaterial, inclinometer casings for lateral movement, and accelerometers for ground vibrations
- Field explorations to evaluate the degree and depth of improvement after the completion of tamping work
- For coarse-grained geomaterial, the field evaluation should be performed at least in 1–2 weeks after the completion of tamping; for fine-grained geomaterial, the evaluation should be performed at least in 3–4 weeks after the completion of tamping
- Field explorations include sampling for laboratory tests, SPT, CPT, or PMT
- The depth of the test should be below the design depth of improvement

THANK YOU

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Module 03: Deep Dynamic Compaction

Lecture 15 : Application Problem

Design Problem

A construction site is a land fill area consist of thin top layer of fine grained soil underlain by a thick layer of clayey silt with varying thickness between 5 to 8 m. The fill has moderate to high degree of saturation. The standard penetration tests were carried out prior to ground improvement work which indicates the site has SPT N-values at various chosen locations range between 6 and 18 with an average value of 9. The required SPT N value required after compaction at least 20. If dynamic compaction is used as a ground improvement technique, provide a preliminary design. To minimize the generation of excess pore water pressure multiple pass construction may be used. Use a tamper weight of 20 ton and with both tamer diameter and height as 1.5 m. Also check for suitability of the method based on the allowable vibration (ppv) when one side of the site exists a residential area at a distance of 20 m and other side a commercial area at a distance of 10 m.

Design steps:

Considering the thickness of the landfill typically ranging from 5.0 to 8.0 m, the depth of improvement is selected as 8.0 m. Based on the composition of the landfill, it can be considered as a semi pervious soil deposit. Since the landfill has a high degree of saturation, the nc value is selected as 0.35. As a result, the required energy per blow can be computed as follows:

$$W_t H_d = \left(\frac{8}{0.35}\right)^2 = 522.4\ kN$$

Type of soil	**Degree of Saturation**	***nc***
Pervious soil deposits – Granular soil	High	0.5
	low	0.5-0.6
Semi-pervious deposits – Primary silts with PI≤8	High	0.35-0.4
	Low	0.4-0.5
Semi-pervious deposits – primary clayey soils with PI>8	High	NR
	Low (w<PI)	0.35-0.4

The contractor provided an 20-t tamper, therefore, the required drop height is 522.4 t-m/20 t = 26.12 m, can be taken as 27 m

Based on Equation $H_d = (W_t H_d)^{0.54}$ gives, almost similar result

Based on the applied energy guidelines, the unit applied energy for landfills ranges from 600 to 1100 kJ/m3. The average unit applied energy is 850 kJ/m3, therefore, the required total applied energy is:

AEtotal = 850x8 = 6800 kJ/m2

Ironing passes are typically used to compact the geomaterial near the surface, which is close to the depth of the craters. Typically, the crater depth ranges from 1.0 to1.5m.The geomaterial above the landfill is most likely fine grained. Since the geomaterial near the surface is above the groundwater table, the unit applied energy for the semi pervious fine-grained soils of 300 kJ/m3 may be used for the ironing passes. Therefore, the required total applied energy for ironing passes is

$$AE_{IP} = 300\ {}^{kJ}/_{m^3} \times 1.5\ m = 450\ {}^{kJ}/_{m^2}$$

Required Unit Applied Energy, UAE

Soil type	Unit applied Energy(KJ/m3)	% of standard proctor energy
Pervious coarse grained soil	200-250	33-41
Semi impervious fine grained soil	250-350	41-60
Landfill	600-1100	100-180

The required total applied energy for high-energy compaction is AEHEP Np = 6.8 MJ/m2 – 0.45 MJ/m 2 = 6.35 MJ/m2. To allow for pore water pressure dissipation during energy application, multiple passes are needed. Assume two passes are adopted. The required applied energy for each pass is 6350/2 = 3175 kJ/m2

Typical drop spacing is 1 ½ to 2 times the tamper diameter. The factor of 2.0 is selected for this site, that is, drop spacing = 2.0 × 1.5 m = 3.0 m (assuming a square pattern). The number of drops at each specific drop point location can be computed by

$$N_{\mathrm{d}} = \frac{AE_{\mathrm{HEP}} \times A_{\mathrm{e}}}{W_{\mathrm{t}} H_{\mathrm{d}}} = \frac{3175 \times 3 \times 3}{20 \times 27 \times 10} = 5.3 \text{ m}$$

Select the number of the drops for each pass at 6. For the number of drops at one location at 6 for each pass, the crater depth can be estimated as follows:

$$D_{\mathrm{cd}} = 0.028\, N_{\mathrm{d}}^{0.55} \sqrt{]W_{\mathrm{t}} H_{\mathrm{d}}} = 0.028 \times 6^{0.55} \sqrt{522.2} = 1.71\, m$$

The allowable crater depth for construction is 1.5 + 0.3 = 1.8 m, which is more than the estimated crater depth expected in the field; therefore, it is OK.

The upper bound of SPT–N value after dynamic compaction ranges from 20 to 40. The induced settlement for uncontrolled fill ranges from 5 to 20%. If the average percentage (i.e., 13%) is considered, the possible induced settlement is 0.13 × 8.0m=1.04 m. However, based on the estimated crater depth, the expected settlement may be estimated as follows (assume the crater diameter is the same as the tamper diameter and no heave). The area ratio of improvement, defined as the area of each crater to the influence area of each tamping point, is:

$$\frac{\pi(1.5/2)^2}{3.0^2} = 0.20$$

The induced settlement by two passes of dynamic compaction = 2×0.20×1.71 = 0.684 m.

Upper Bound Test Values after Dynamic Compaction

Soil type	SPT N value	CPT MPa	
Pervious coarse grained soil: Sands and Gravel	40-50	19-29	
Semi-impervious soils			
Sands and Gravel	40-50	19-29	
Silts and clayey silts	25-35	10-13	
Partially saturated impervious deposits			
Clay fills and mine spoil	30-40	NA	
Landfills	20-40	NA	

Approximate Induced Settlement as Percent of Improvement Depth

Soil type	Percent of depth
Natural clays	1-3
Clay fills	3-5
Natural sands	3-10
Granular fills	5-15
Uncontrolled fills	5-20

$$PPV = 70\left(\frac{\sqrt{W_{\mathrm{t}}H_{\mathrm{d}}}}{x_{\mathrm{dp}}}\right)^{1.4}$$

Typical Threshold Particle Velocity

Structure Type	Velocity(mm/s)
Commercial, industrial	20-40
Residential	5-15
Sensitive	3-5