NPTEL Course

GROUND IMPROVEMENT

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Deep Compaction and Objectives

Compaction

➢ Deep compaction techniques are required when in–situ soil extending to large depths does not meet the requirements of performance criteria specified for the expected loading and environmental conditions.

➢ Deep soil improvement is possible by resorting to

- Ground Improvement Techniques
- Ground Reinforcement Techniques
- Ground treatment

Ground Improvement

- Dynamic Compaction
- Vibro-Compaction
- Compaction Grouting
- Pre-fabricated Vertical Drains
- Blast densification

Dynamic Compaction

➢ Technique

➢ Design

➢ Evaluation

➢ Effectiveness

Format

- Technique

- Energy transfer mechanism

- Stages of compaction

- Application – which soils are compacted?

- Types

- Ground Vibrations

- Design Considerations

TECHNIQUE

- Technique involves repeatedly dropping a large weight from a crane

- Weight may range from 6 to 172 tons

- Drop height typically varies from 10 m to 40 m

- Degree of densification achieved is a function of the energy input (weight and drop height) as well as the saturation level, fines content and permeability of the material

- 6 – 30 ton weight can densify the loose sands to a depth of 3 m to 12 m

W = Mass of tamper.
H = Drop height.
D = Maximum depth of improvement.
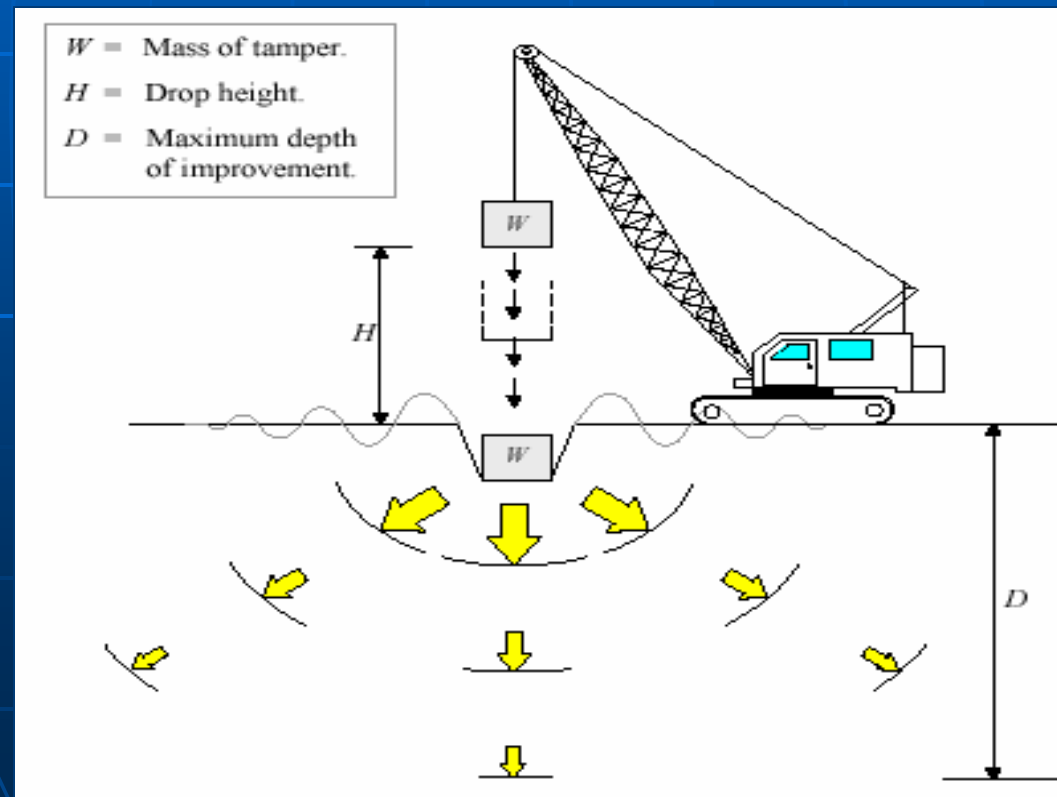
- Done systematically in a rectangular or triangular pattern in phases

- Each phase can have no of passes; primary, secondary, tertiary, etc.
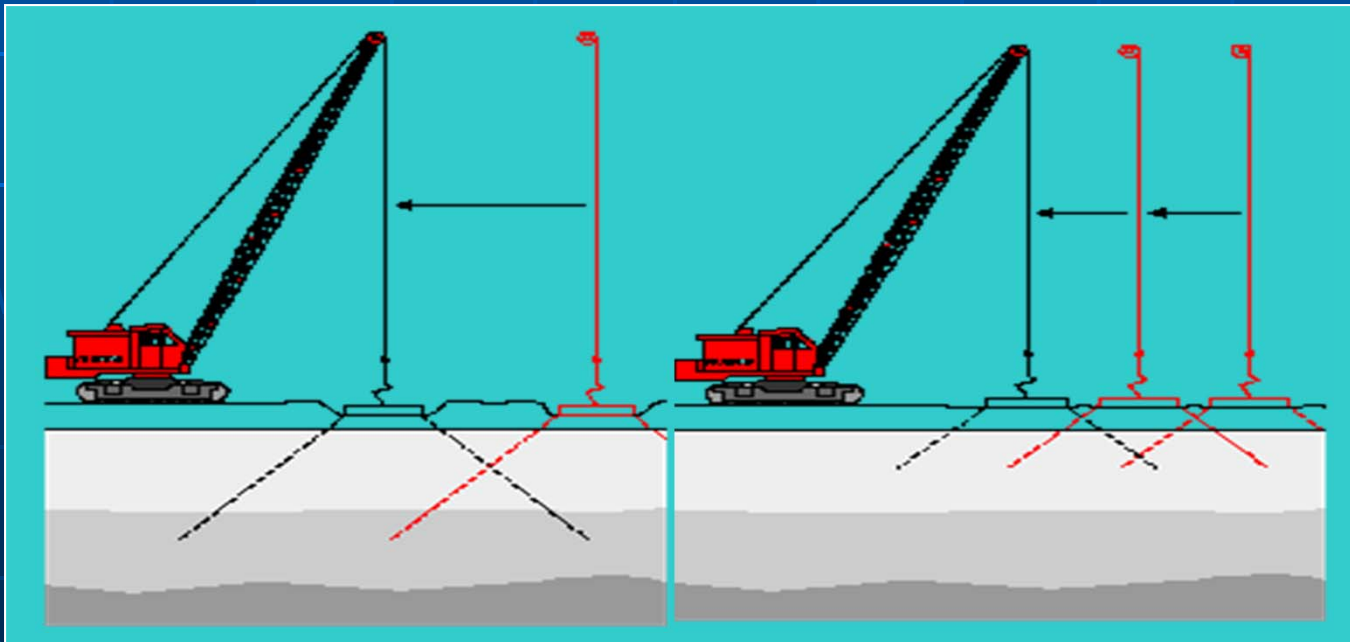

(a)

(b)

LEGEND

○ Primary Pass

○ Secondary Pass
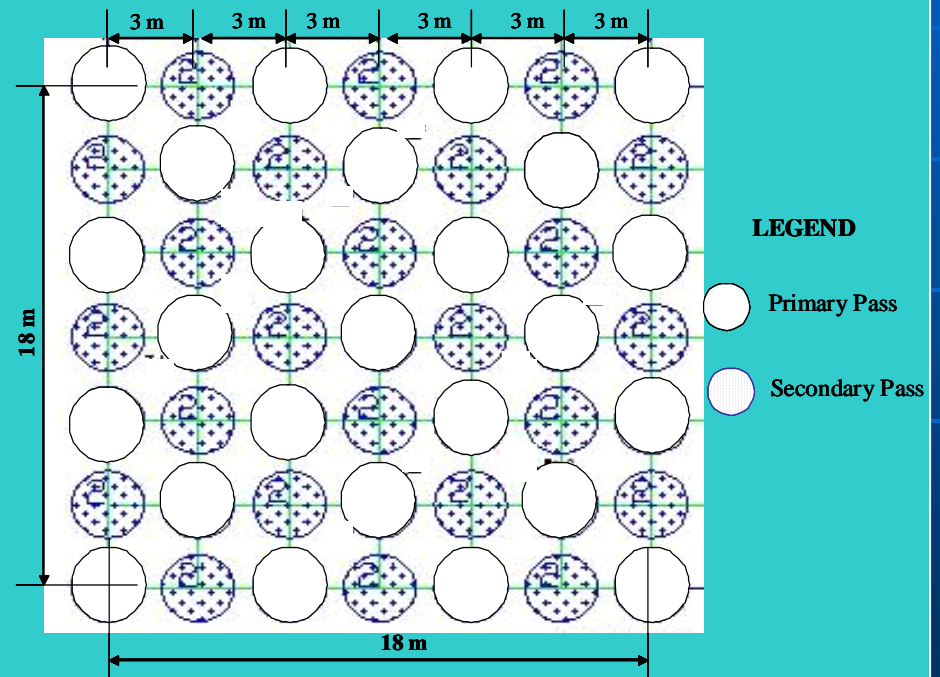
- Spacing between impact points depend upon:
  - Depth of compressible layer
  - Permeability of soil
  - Location of ground water level
- Deeper layers are compacted at wider grid spacing, upper layers are compacted with closer grid spacing

- Deep craters are formed by tamping

- Craters may be filled with sand after each pass

- Heave around craters is generally small
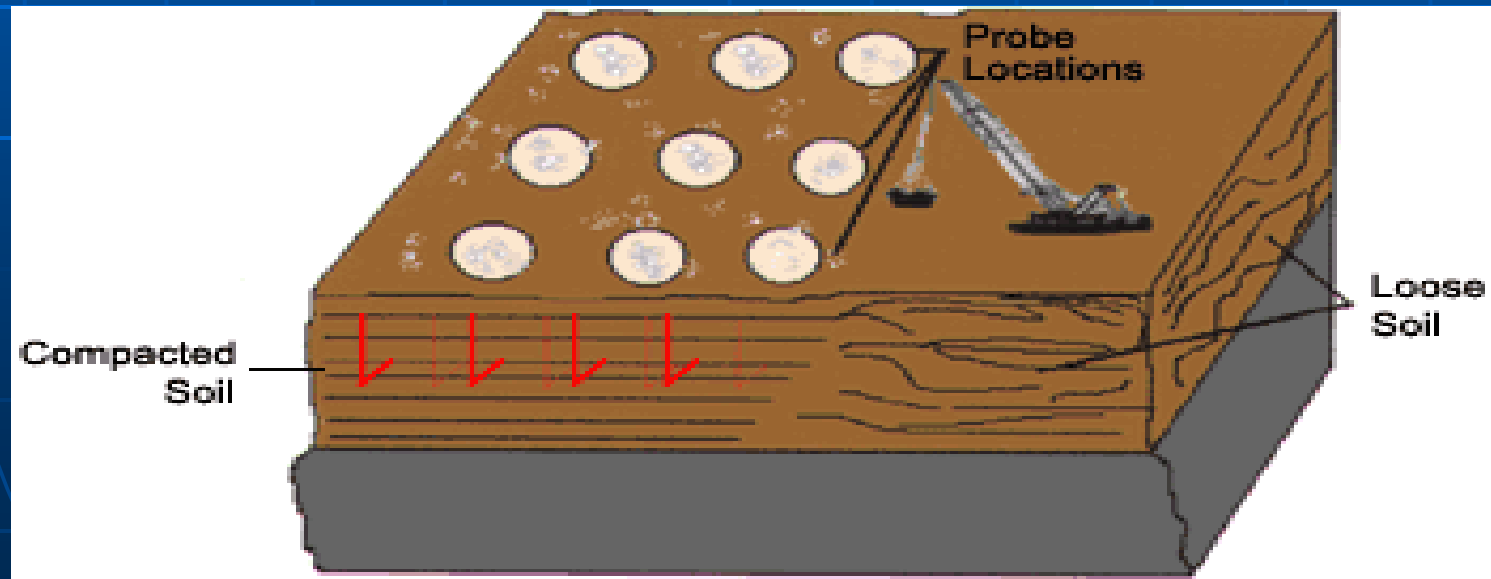
ENERGY TRANSFER MECHANISM

➢ Energy transferred by propagation of Rayleigh (surface) waves and volumic (shear and compression) waves

➢ Rayleigh   67 %

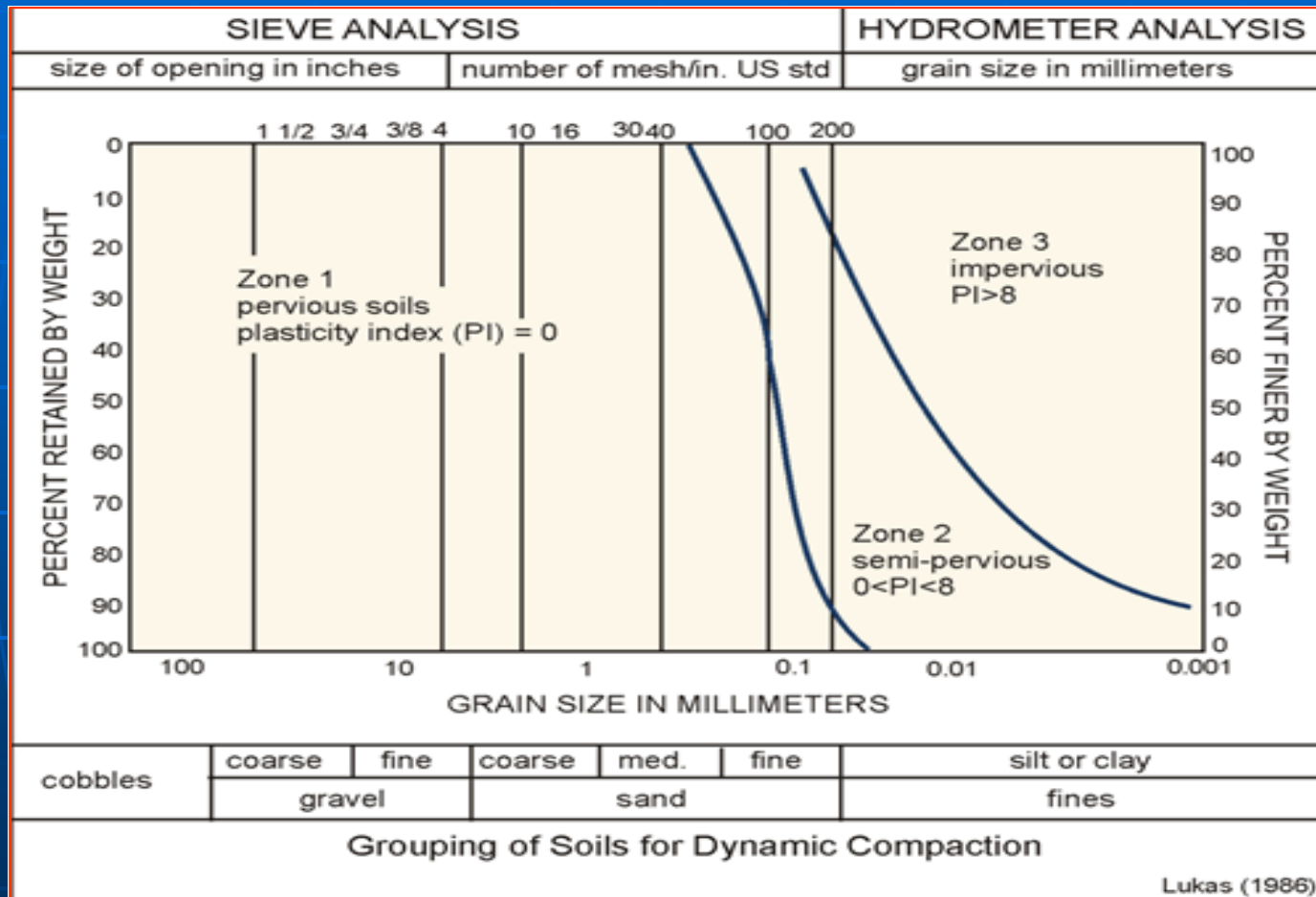➢ Shear   26 %

➢ Compression   7%
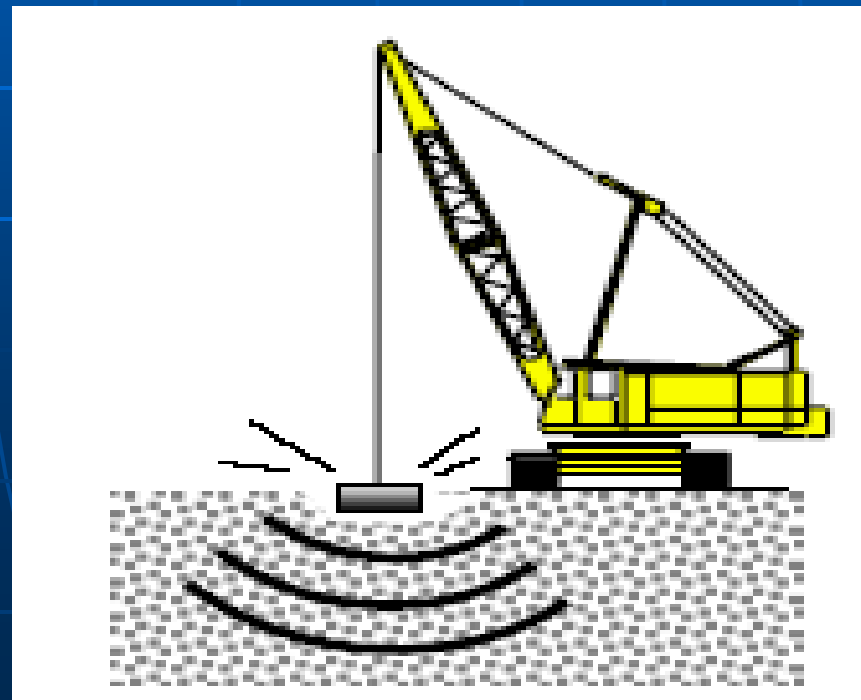
DENSIFICATION PROCESS

- Compressibility of saturated soil due to presence of micro bubbles

- Gradual transition to liquefaction under repeated impacts

- Rapid dissipation of pore pressures due to high permeability after soil fissuring

- Thixotropic recovery

- Applicable to wide variety of soils

- Grouping of soils on the basis of grain sizes

SIEVE ANALYSIS		HYDROMETER ANALYSIS
size of opening in inches	number of mesh/in. US std	grain size in millimeters

Zone 1
pervious soils
plasticity index (PI) = 0

Zone 3
impervious
PI>8

Zone 2
semi-pervious
0<PI<8

PERCENT RETAINED BY WEIGHT

PERCENT FINER BY WEIGHT

GRAIN SIZE IN MILLIMETERS

cobbles	coarse	fine	coarse	med.	fine	silt or clay
	gravel		sand			fines

Grouping of Soils for Dynamic Compaction

Lukas (1986)

Zone 1: Best
Zone 3: Worst (consider alternate methods)
Zone 2: Must apply multiple phases to allow for pore pressure dissipation

- Mainly used to compact granular fills

- Particularly useful for compacting rockfills below water and for bouldery soils where other methods can not be applied or are difficult

- Waste dumps, sanitary landfills, and mine wastes

- In sanitary fills, settlements are caused either by compression of voids or decaying of the trash material over time, DDC is effective in reducing the void ratio, and therefore reducing the immediate and long term settlement.

- DDC is also effective in reducing the decaying problem, since collapse means less available oxygen for decaying process.

- For recent fills where organic decomposition is still underway, DDC increases the unit weight of the soil mass by collapsing voids and decreasing the void ratio.

- For older fills where biological decomposition is complete, DDC has greatest effects by increasing unit weight and reducing long term ground subsidence.

TYPES
OF
DYNAMIC COMPACTION

TYPES OF DYNAMIC COMPACTION

- Dynamic compaction

- Dynamic consolidation

- Dynamic replacement

- Rotational dynamic compaction

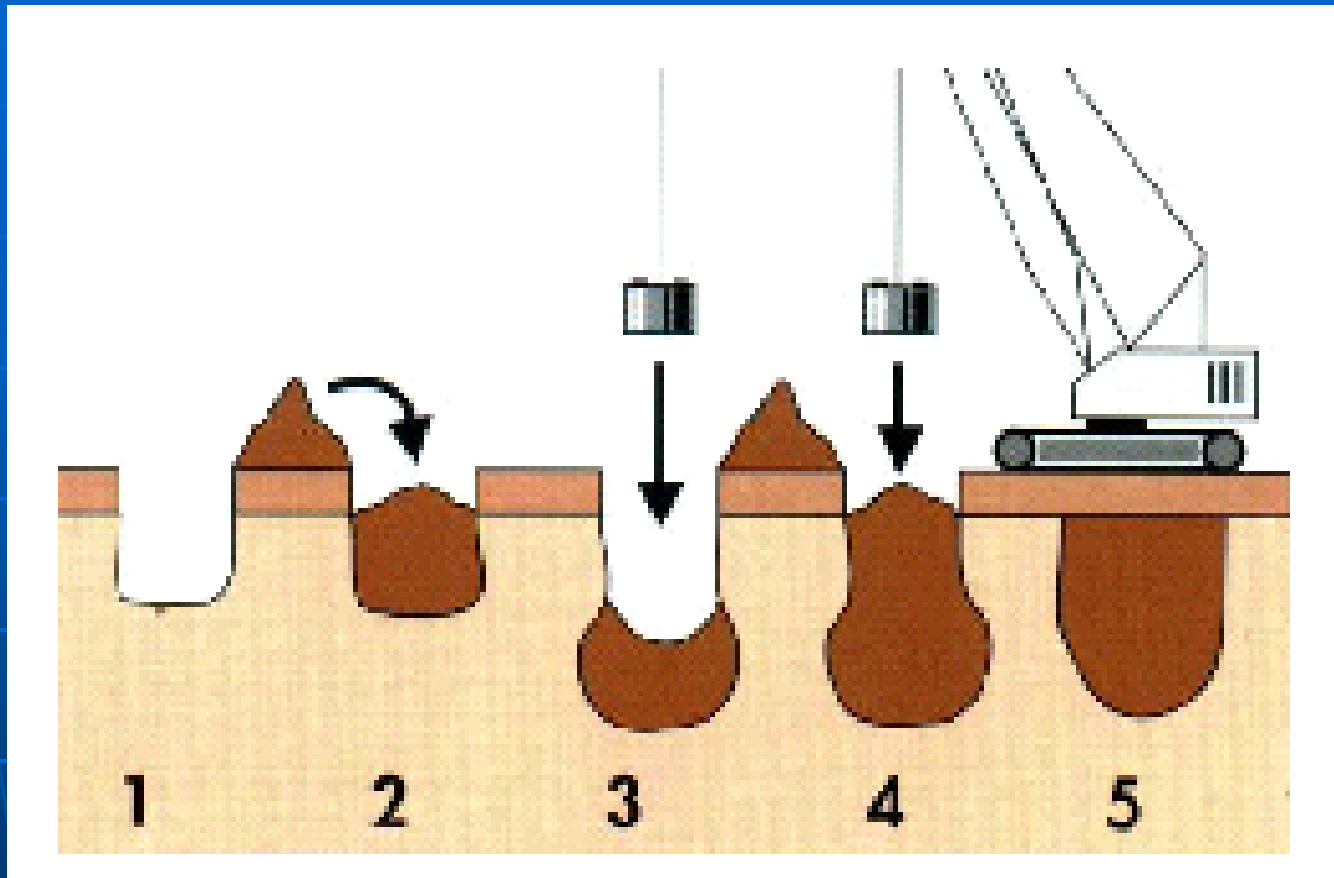- Rapid impact dynamic compaction

Dynamic Compaction

➢ It is the compaction of unsaturated or highly permeable saturated granular materials by heavy tamping

➢ The response to tamping is immediate

Dynamic Consolidation

➤ The improvement by heavy tamping of saturated cohesive materials in which the response to tamping is largely time dependent

➤ Excess pore water pressures are generated as a result of tamping and dissipate over several hours or days after tamping.

Dynamic Replacement

➢The formation by heavy tamping of large pillars of imported granular soil within the body of soft saturated soil to be improved

➢The original soil is highly compressed and consolidated between the pillars and the excess pore pressure generated requires several hours to dissipate

➢The pillars are used both for soil reinforcement and drainage

Process of Dynamic Replacement

Rotational Dynamic Compaction

➢A new dynamic compaction technique which makes use of the free fall energy as well as rotational energy of the tamper called Rotational Dynamic Compaction (RDC)

➢The technique increases depth of improvement in granular soils

➢Comparative study showed that the cone penetration resistance was generally larger than conventional dynamic compaction and the tamper penetration in rotational dynamic compaction was twice as large as that of conventional dynamic compaction
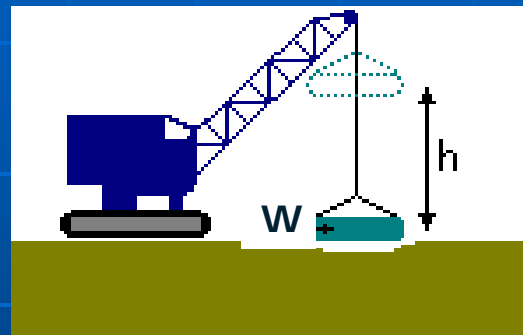
Rotational Dynamic Compaction
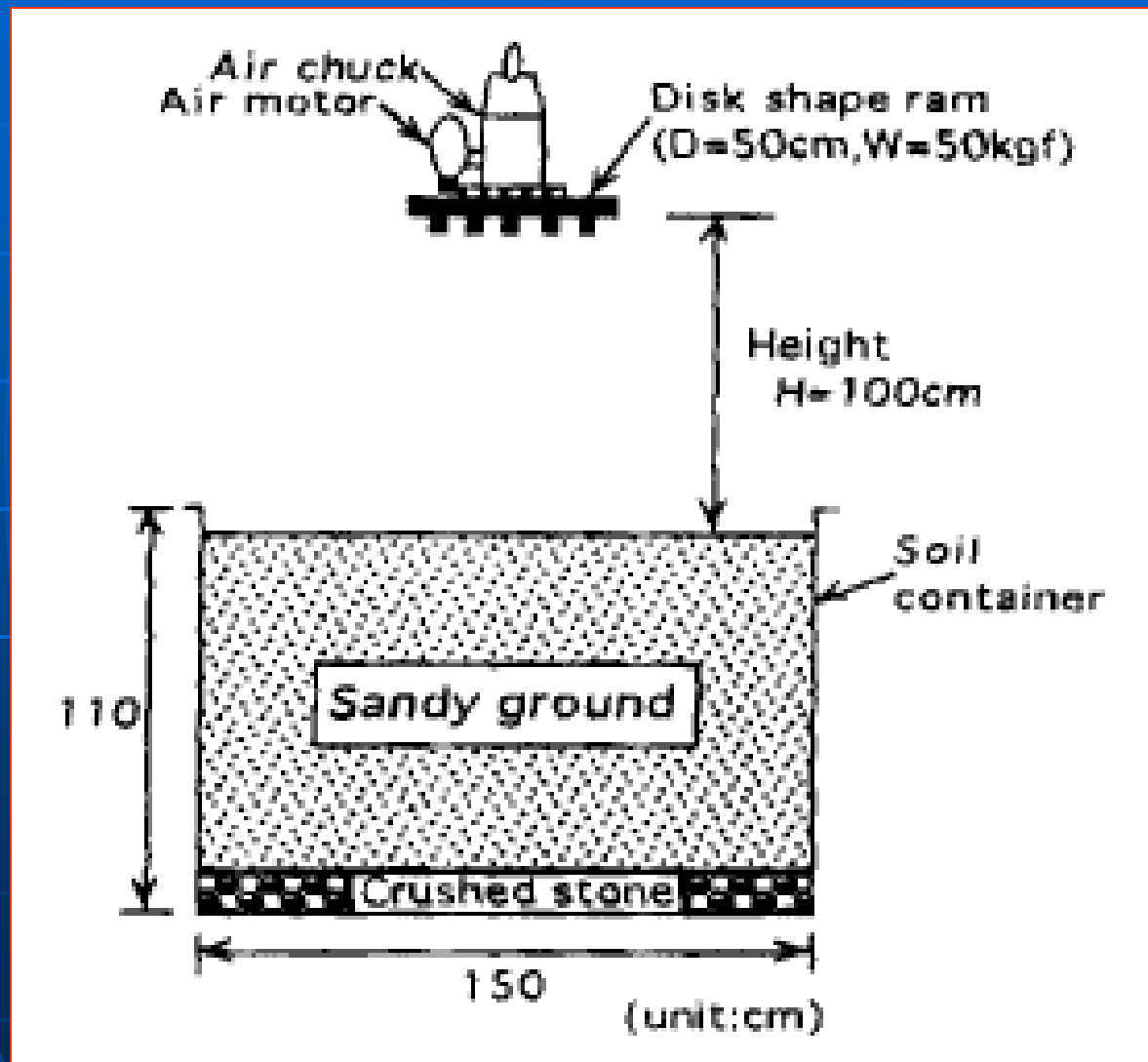
Rapid Impact Dynamic Compaction

EVALUATION
OF
IMPROVEMENT

EVALUATION OF IMPROVEMENT

➢ The depth of improvement is proportional to the energy per blow

➢ The improvement can be estimated through empirical correlation, at design stage and is verified after compaction through field tests such as Standard Penetration Tests (SPT), Cone Penetration Test (CPT), etc.

$$D_{max} = n\sqrt{W} \times H$$

Where,

D_{max} = Max depth of improvement, m

n = Coefficient that caters for soil and equipment variability

W = Weight of tamper, tons

H = Height of fall of tamper, m

❑The effectiveness of dynamic compaction can also be assessed readily by the crater depth and requirement of backfill

Reference	N-Values
Menard and Broise (1975)	1.0
Leonard et al. (1980)	0.5
Bjolgerud and Han (1963)	1.0 (rockfill)
Smoltcyk (1983)	0.5 (soil with unstable structure) 0.67 (silts and sands) 1.0 (purely frictional sand)
Lukas (1980)	0.65 - 0.8
Mayne et al. (1984)	0.3 - 0.8
Gambin (1984)	0.5 – 1.0
Qian (1985)	0.65 (fine sand) 0.66 (soft clay) 0.55 (loess)
Van Impe (1989)	0.65 (silty sand) 0.5 (clayey sand)

GROUND VIBRATIONS

- Dynamic compaction generates surface waves with a dominant frequency of 3 to 12 Hz

- These vibrations generate compression, shear and Rayleigh waves

- The Raleigh waves contain about 67 percent of the total vibration energy and become predominant over other wave types at comparatively small distances from the source

- Raleigh waves have the largest practical interest for the design engineers because building foundations are placed near the ground surface

➢ The ground vibrations are quantified in terms of peak particle velocity (PPV); the maximum velocity recorded in any of the three coordinate axes

➢ The measurement of vibrations is necessary to determine any risk to nearby structures

➢ The vibrations can be estimated through empirical correlations or measured with the help of instruments such as portable seismograph, accelerometers, velocity transducers, linear variable displacement transducers (LVDT), etc.

- The frequency of the Raleigh waves decreases with increasing distance from the point of impact

- Relationship between PPV and inverse scaled distance is shown graphically (the inverse scaled distance is the square root of the compaction energy, divided by the distance, d from the impact point)
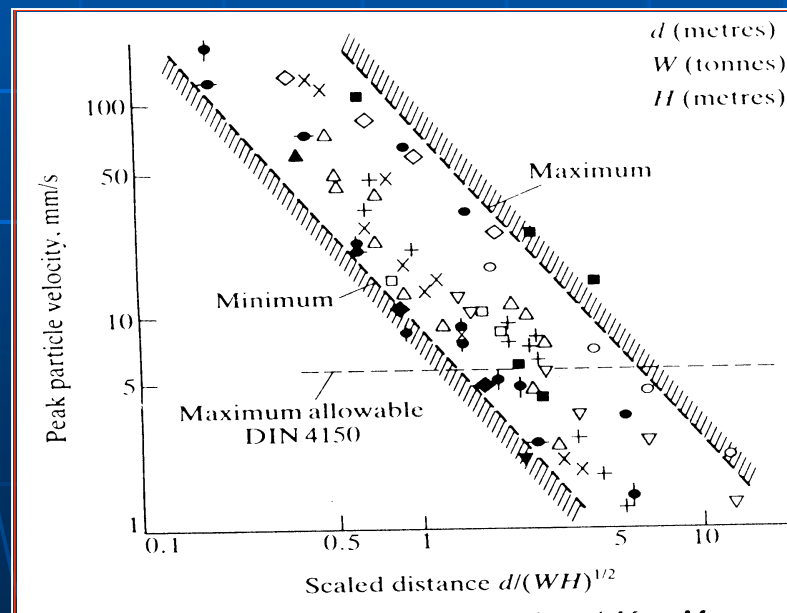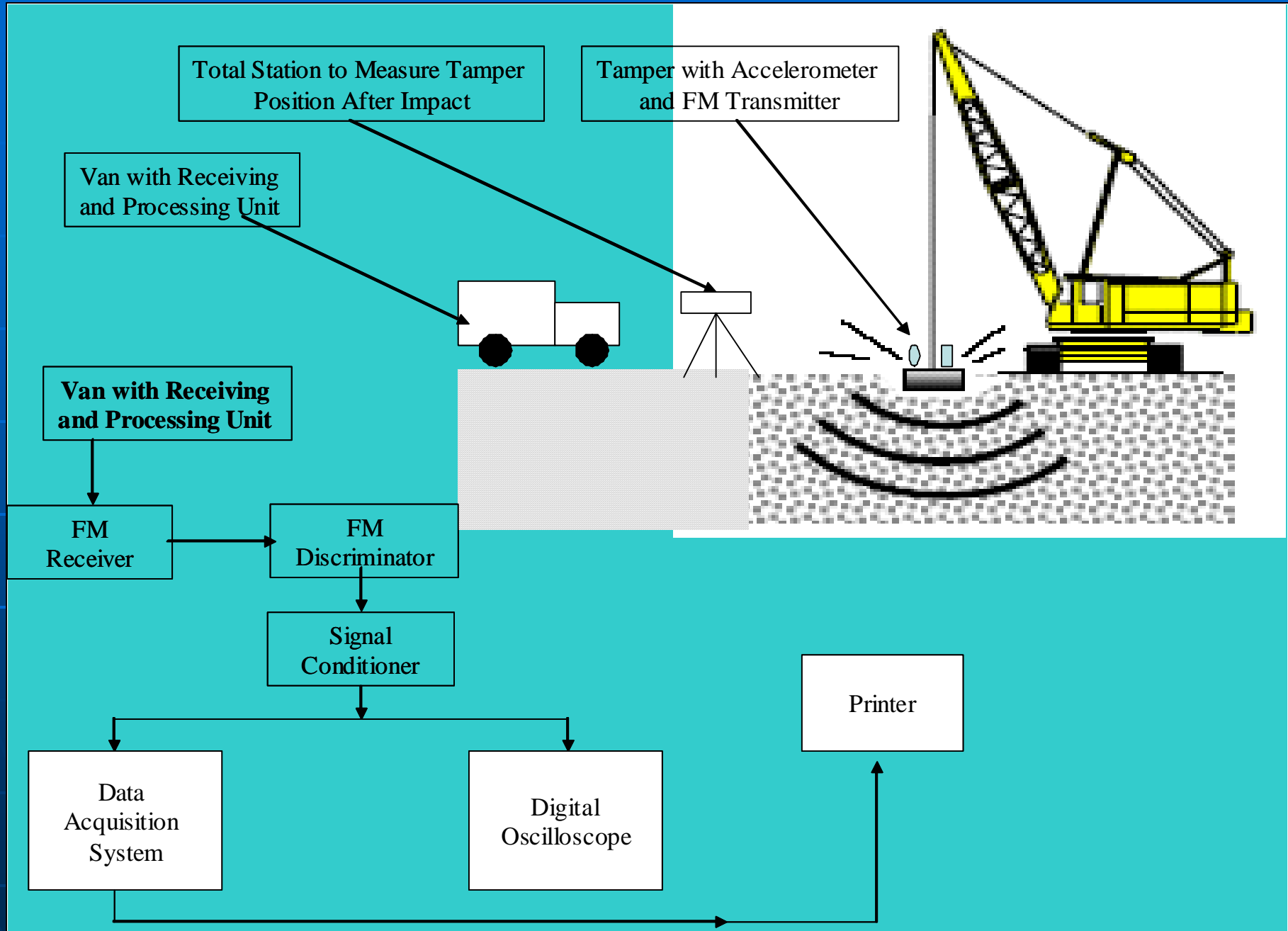
Tolerance Limits for Structures

British Standard 7385: Part 2-1993, lays down following safety limits for various structures having different natural frequencies:

➤ Reinforced or framed structures industrial and heavy commercial buildings at 4 Hz and above   50 mm/s

➤ Un-reinforced or light framed structures residential or light commercial type buildings at 4 Hz –15 Hz   15-20 mm/s

➤ Un-reinforced or light framed   residential or light commercial type buildings at 15 Hz –40 Hz and above

20-50 mm/s

Effect on Humans

- 0.1 mm/sec   not noticeable
- 0.15 mm/sec   nearly not noticeable
- 0.35 mm/sec   seldom noticeable
- 1.00 mm/sec   always noticeable
- 2.00 mm/sec   clearly noticeable
- 6.00 mm/sec   strongly noticeable
- 14.00 mm/sec   very strongly noticeable
- 17.8 mm/sec   severe noticeable

MONITORING AND CONTROL

Total Station to Measure Tamper
Position After Impact

Tamper with Accelerometer
and FM Transmitter

Van with Receiving
and Processing Unit

**Van with Receiving
and Processing Unit**

FM
Receiver

FM
Discriminator

Signal
Conditioner

Data
Acquisition
System

Digital
Oscilloscope

Printer

DESIGN AND ANALYSIS CONSIDERATIONS

- Depth of improvement, d

- Impact energy, E

- Influence of cable drag

- Equipment limitations

- Influence of tamper size

- Grid spacing, S

- Time delay between passes

- Soil conditions

Depth of Improvement

Primary concern

➤ Depends on:

❖ Soil conditions

❖ Energy per drop

❖ Contact pressure of tamper

❖ Grid spacing

❖ Number of passes

❖ Time lag between passes

Impact Energy, E

➢ Weight of tamper times the height of drop

➢ Main parameter in determining the depth of improvement

➢ Can be calculated from the equation

$$D_{max} = n\sqrt{W} \times H$$

(Free falling of weights)

Influence of Cable Drag

➢ Cable attached to the tamper causes friction and reduces velocity of tamper

➢ Free fall of tamper is more efficient

Equipment limitations

➢ Crane capacity

➢ Height of drop
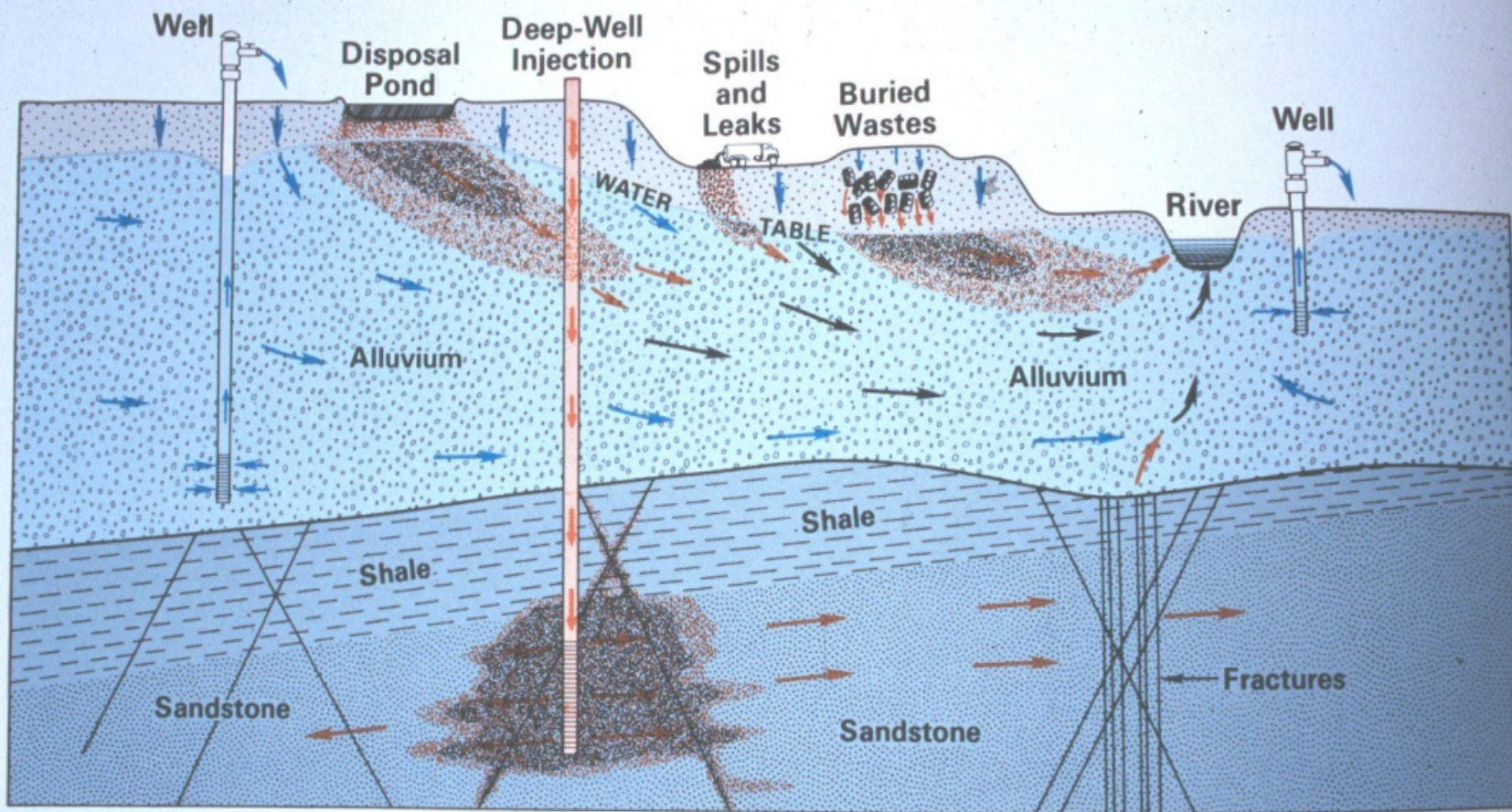
➢ Mass of tamper

➢ Tamper size

Grid Spacing

➤ Significant effect on depth of improvement

➤ First pass compacts deepest layer, should be equal to the compressible layer

➤ Subsequent passes compact shallower layers, may require lesser energy

➤ Ironing pass compacts top layer

Time Delay between Passes

➢ Allow pore pressures to dissipate

➢ Piezometers can be installed to monitor dissipation of pore pressures following each pass

Industrial wastes are disposed of in many ways