Construction Planning, Equipment, and Methods

Sixth Edition

CHAPTER

4c

GEOTECHNICAL MATERIALS, COMPACTION, AND STABILIZATION

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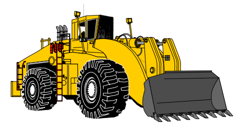

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COMPACTION CONTROL

- The specifications for a project may require a contractor to compact the soil to to a 100% relative density, based on standard Proctor test or a laboratory test at some other energy level.

COMPACTION CONTROL

- If the maximum laboratory density of the soil is determined to be 120 lb per cu ft, the contractor must compact the soil to a density of 120 lb per cu ft.

COMPACTION CONTROL

- Field verification tests of achieved compaction can be conducted by any of several accepted methods:
  1) Sandcone
  2) Balloon
  3) Nuclear

COMPACTION CONTROL

- The first two methods are destructive tests. They involve
  - ✓excavating a hole in the compacted fill and weighing the excavated material.
  - ✓determining the water content of the excavated material.
  - ✓measuring the volume of the resulting hole.

COMPACTION CONTROL

- Disadvantages of using sandcone and balloon methods:
  1) time-consuming to conduct sufficient tests for statistical analysis.
  2) problems with oversized particles.
  3) the determination of water content takes time

NUCLEAR COMPACTION TEST

- Nuclear methods are used extensively to determine the water content and density of soils.
- The instrument required for this test can be easily transported to the fill, placed at the desired test location, and within a few minutes the results can be read directly from the digital display.

NUCLEAR COMPACTION TEST

- **Advantages of the nuclear method when compared with other methods include the following:**
  1) Decreases the time required for a test from as much as a day to a few minutes, thereby eliminating potentially excessive construction delays.

NUCLEAR COMPACTION TEST

2) It is nondestructive in that it does not require the removal of soil samples from the site of the tests.
3) Provides a means of performing density tests on soils containing large-sized aggregates and on frozen materials.
4) Reduces or eliminates the effect of the personal element, and possible errors. Erratic results can be easily and quickly rechecked.

NUCLEAR COMPACTION TEST

- **Disadvantages of the nuclear method when compared with other methods include the following:**
  1) Nuclear test instruments, it not used properly, present a potential source of radiation that can be harmful to humans

NUCLEAR COMPACTION TEST

2) These instruments usually require a skilful operator who exercise care to ensure that no harm can result from the use of the instruments.
3) In the U.S., a license is required to possess, own, or use nuclear-type instruments

GEOGAUGE

- A Geogauge device is a nondestructive devise that does not require the removal of soil samples from the site of the tests.
- This device is very ***new*** to the field.
- The Minnesota Department of transportation tested the first prototype models in 1994.

GEOGAUGE

- Production models are currently available and each year more agencies are conducting independent field evaluation.
- This portable device can provide a *simple*, *rapid*, and *precise* means of directly measuring lift stiffness and soil modulus.

LABORATORY VERSUS FIELD

- Maximum dry density is only a maximum for a specific compaction effort (input energy level) and the method by which that effort is applied.

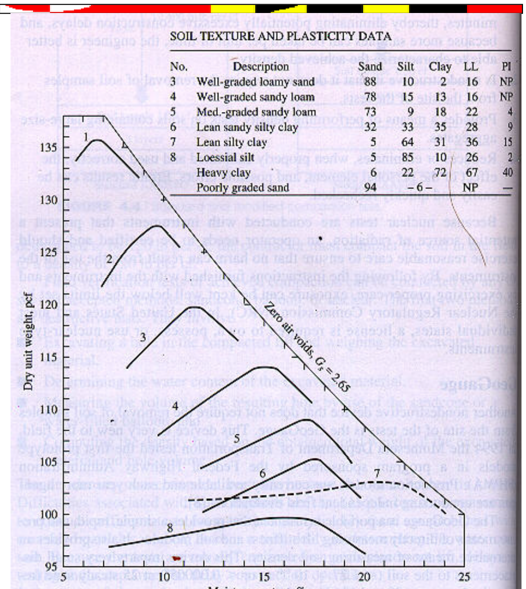
LABORATORY VERSUS FIELD

- If more energy is applied in the field, a density greater than 100% of the laboratory value can be achieved.
- Dissimilar materials have individual curves and maximum values for the same input energy as shown in the following figure (Figure 7)

LABORATORY VERSUS FIELD

Figure 7

Comparison Curves for Eight Soils Compacted according to AASHTO T99
(Highway Research Board)



SOIL TEXTURE AND PLASTICITY DATA

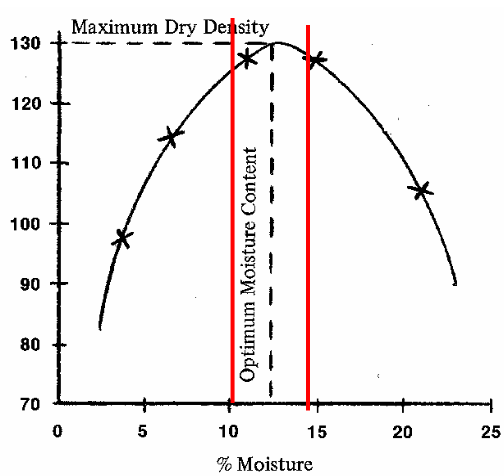
No.	Description	Sand	Silt	Clay	LL	PI
3	Well-graded loamy sand	88	10	2	16	NP
4	Well-graded sandy loam	78	15	13	16	NP
5	Med.-graded sandy loam	73	9	18	22	4
6	Lean sandy silty clay	32	33	35	28	9
7	Lean silty clay	5	64	31	36	15
8	Loessial silt	5	85	10	26	2
	Heavy clay	6	22	72	67	40
	Poorly graded sand	94	– 6 –		NP	—

SOIL PROCESSING

- The optimum water content (ω)
  - ✓ **Fine-grained soils** – from 12 to 25%
  - ✓ **Well-graded granular** – from 7 to 12%
  - ✓ **Normal Practice** to work at ±2% of optimum or 95% of maximum dry unit weight.

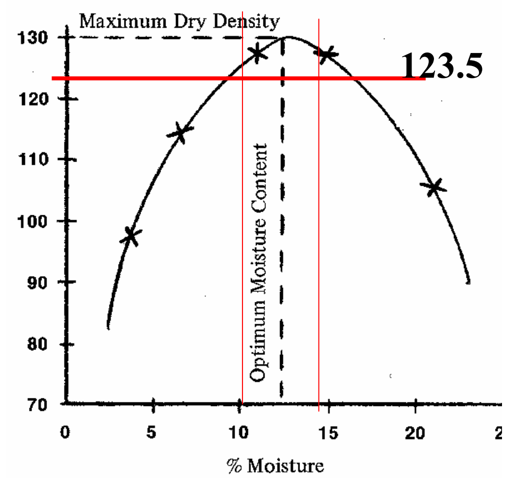
COMPACTION SPECIFICATIONS

Typically specifications give an acceptable range of water content, OMC ± 2% for example.



COMPACTION SPECIFICATIONS

The specification also sets a minimum density, 95% of max. dry density for a specific test.

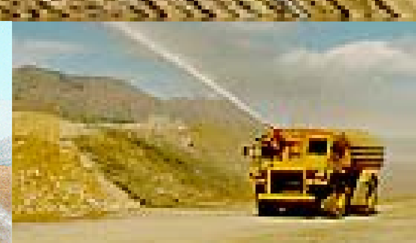


SOIL PROCESSING

- Adding Water to Soil
  - ✓Water must be added prior to compaction if the water content (ω) is below the optimum moisture range.
  - ✓Water can be added to soil at the borrow pit or in-place (at the construction site).

ADDING WATER TO SOIL

ADDING WATER TO SOIL



SOIL PROCESSING

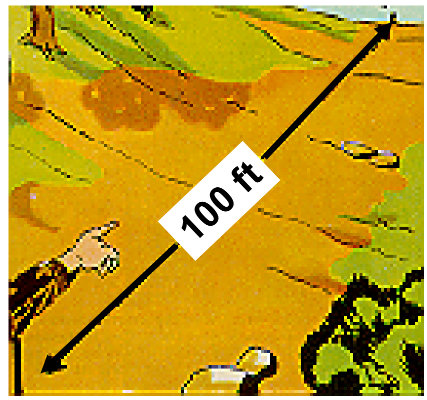
- When it necessary to add water, the following items are to be considered:
  - ✓Amount of water required.
  - ✓Rate of water application.
  - ✓Method of application.
  - ✓Effects of the climate and weather.

SOIL PROCESSING

- **Amount of Water Required**
  - ✓It is important to determine the amount of water required to achieve a soil water content (ω) within the acceptable range for compaction.
  - ✓The amount of water that must added or removed is normally computed in gallons per station (100 ft length).

Earthwork

The horizontal dimensions of a project are in stations. One station equals 100 ft.



SOIL PROCESSING

- **Amount of Water Required**
  - ✓ **The following formula can used to compute the amount of water added or removed from soil:**

$$\text{Gallons} = \text{desired dry density (pcf)} \times \frac{(\text{desired water content \%}) - (\text{water content borrow \%})}{100} \times \frac{\text{compacted volume of soil (cf)}}{8.34 \text{ lb per gallon}} \qquad \textbf{(37a)}$$

WATER REQUIREMENT

Gallons, water requirements =

$$\gamma_d \text{ emb (pcf)} \times \frac{\omega \text{ emb}(\%) - \omega \text{ cut}(\%)}{100} \times \frac{\text{Vol. emb(cf)}}{8.33} \qquad \textbf{(37b)}$$

SOIL PROCESSING

- **Water Application Rate**
  - ✓ **Once the total amount of water has been calculated, the application rate can be calculated. The following formula can be used:**

Gallons per square yard =

$$\gamma_d \text{emb (pcf)} \times \frac{\omega \text{ emb } (\%) - \omega \text{ cut } (\%)}{100} \times \text{lift thickness (ft) (compacted)} \times \frac{9 \text{ sf / sy}}{8.34 \text{ lb /gal}} \qquad \textbf{(38)}$$

Example 6

Job specifications require placement of the embankment fill soil in 6-in. (compacted) fills. The desired dry unit weight of the embankment is 120 pcf. The laboratory compaction curve indicates that the optimum water content (OMC) of the soil is 12%. Soil tests indicated that the moisture content of the borrow material is 5%. The

Example 6 (cont'd)

roadway lift to be placed is 40 ft wide. Compute the amount of water in gallons to add on a per station basis for each lift material.

$$\text{Gallons} = 120\ \text{pcf} \times \left(\frac{12-5}{100}\right) \times \frac{(40\ \text{ft} \times 100\ \text{ft} \times 0.5\ \text{ft})}{8.34\ \text{lb/gal}}$$

$$= 2{,}015\ \text{gallons per station}$$

Example 7

Using the data from Example 6, determine the required application rate in gallons per square yard.

Using Eq. 38, we have

$$\text{Gallons per square yard} = 120\text{ pcf} \times \left(\frac{12-5}{100}\right)(0.5\text{ ft}) \times \frac{9\text{ sf / sy}}{8.34\text{ lb /gal}}$$

$$= 4.5\text{ gallons per sy}$$

COMPACTION OF GEOTECHNICAL MATERIALS

- Engineering properties of soils can be improved by compaction. Compaction can:
  - ✓Reduce or prevent settlements.
  - ✓Increase strength.
  - ✓Improve bearing capacity.
  - ✓Control volume changes.
  - ✓Lower permeability.

COMPACTION OF GEOTECHNICAL MATERIALS

- Because there is a correlation between compaction properties and dry density, construction documents usually call for achieving a specified density.
- There may be other methods whereby the desired compaction properties can be attained.

COMPACTION OF GEOTECHNICAL MATERIALS

- By far the most widely used method of soil strengthening for use as a subgrade under a pavement structure or other foundation is compaction of the soil at optimum moisture.

COMPACTION OF GEOTECHNICAL MATERIALS

- Typically, a uniform layer, or lift, of soil from 4 to 12 in thickness is compacted by means of several passes of heavy mechanized compaction equipment.
- It should be noted that good compaction can cost more money.

COMPACTION SPECIFICATIONS

- Specifications governing compaction may be one of the following types:
  a) Method only (often termed "recipe").
  b) End result only (often termed "performance").
  c) Method and end result.

FIELD COMPACTION

- Densification is accomplished by:
  - ✓Static weight (pressure)
  - ✓Kneading (manipulation)
  - ✓Impact (sharp blow)
  - ✓Vibration (shaking)

FIELD COMPACTION

- Ordinary compaction in the field is accomplished by means of rollers
- Several types of rollers are used:
  - ✓Smooth wheel rollers (drum rollers).
  - ✓ Pneumatic rubber-tired rollers.
  - ✓ Sheepsfoot rollers (Tamping rollers).
  - ✓ Vibratory rollers.

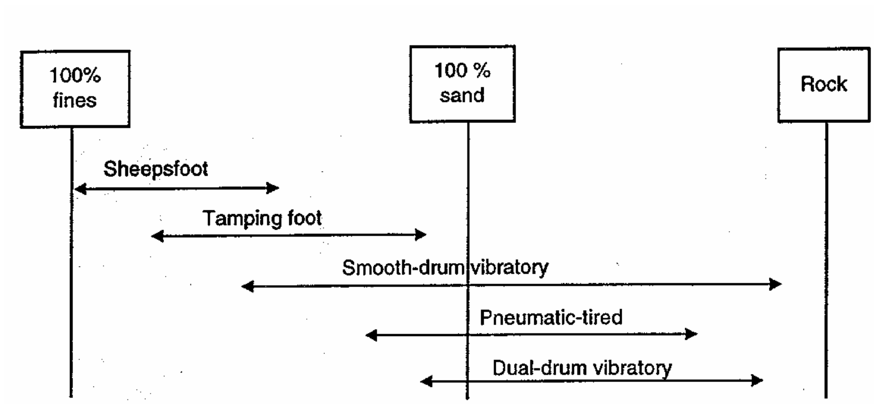
SMOOTH-WHEEL ROLLERS

- ✓Smooth-wheel rollers are suitable for proof-rolling subgrades and for finishing operation of fills with sandy and clayey soils.
- ✓They provide 100% coverage under the wheels with ground contact pressures as high as 45 to 55 lb/in^2.
- ✓They are not suitable for producing high unit weights of compaction when used on relatively thick layers.

SMOOTH-WHEEL ROLLERS

COMPACTION

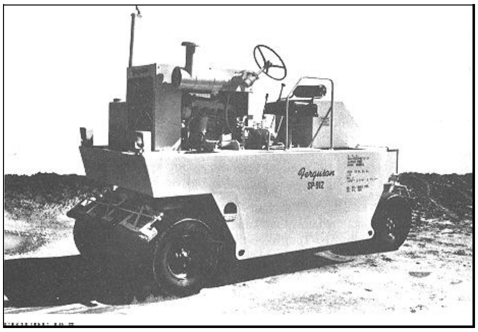
Roller Capabilities



PNEUMATIC RUBBER-TIRED ROLLERS

- ✓Pneumatic rubber-tired rollers are better in many than smooth-wheel rollers.
- ✓They are heavily-loaded wagons with several rows rows of tires.
- ✓The tires are closely spaced, four to six in a row.
- ✓They provide 70% to 85% coverage under the wheels with ground contact pressures as high as 85 to 100 lb/in^2.

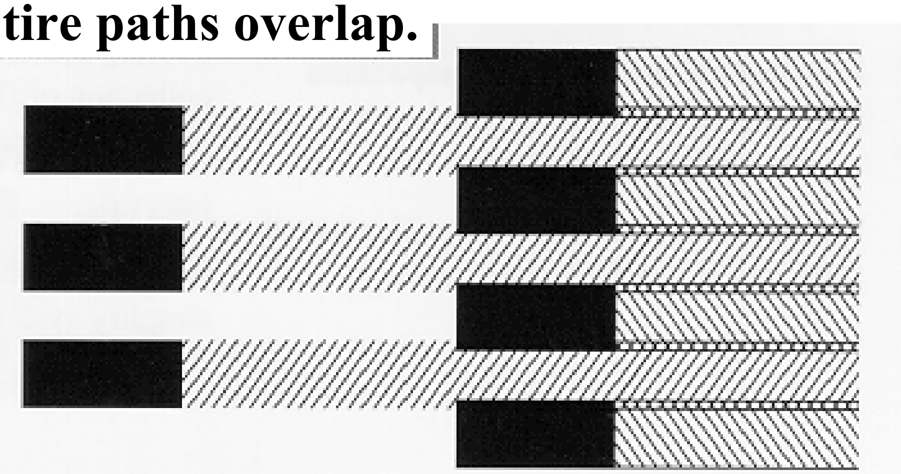
PNEUMATIC RUBBER-TIRED ROLLERS



PNEUMATIC

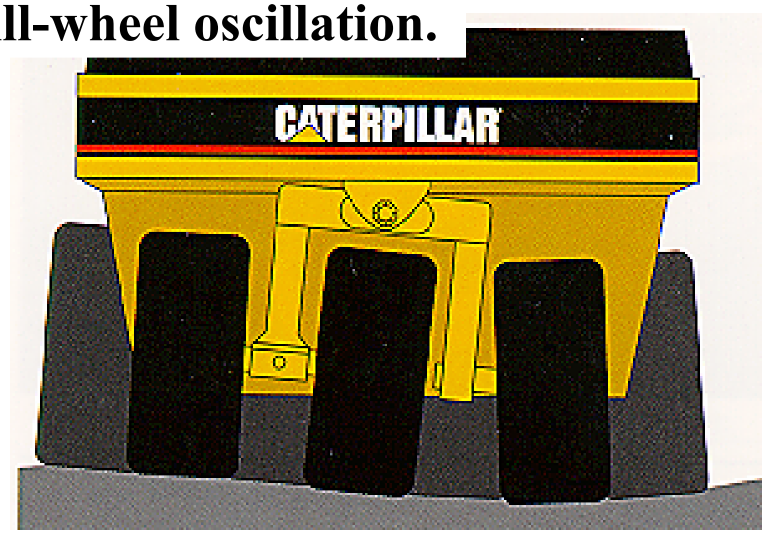
PNEUMATIC

Front and rear tire paths overlap.



PNEUMATIC

All-wheel oscillation.



PNEUMATIC COMPACTOR

Pneumatic-tired (rubber-tired) rollers are suitable for compacting most granular soils.

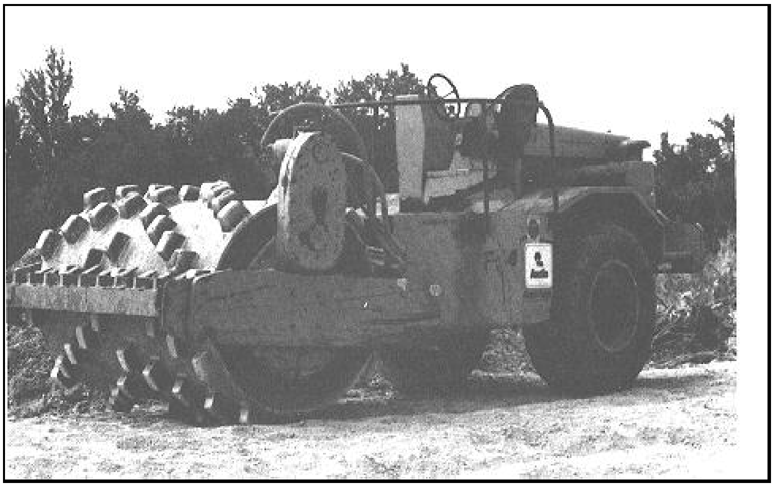
They are not effective in compacting fine-grained clays.

They compact by static-load and kneading action.

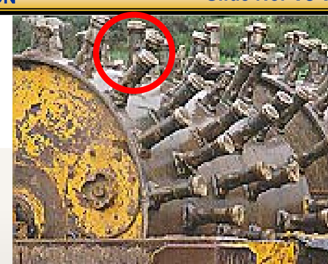
SHEEPSFOOT ROLLERS

- ✓Sheepsfoot rollers are drums with a large number of projections.
- ✓The area of each of these projections may range from 4 to 13 in^2.
- ✓These rollers are most effective in compacting clayey soils.
- ✓The contact pressure under the projections can range from 200 to 1000 lb/in^2.

SHEEPSFOOT ROLLERS



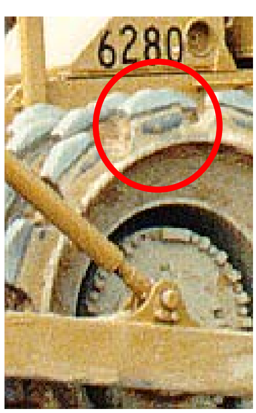
SHEEPS FOOT ROLLER

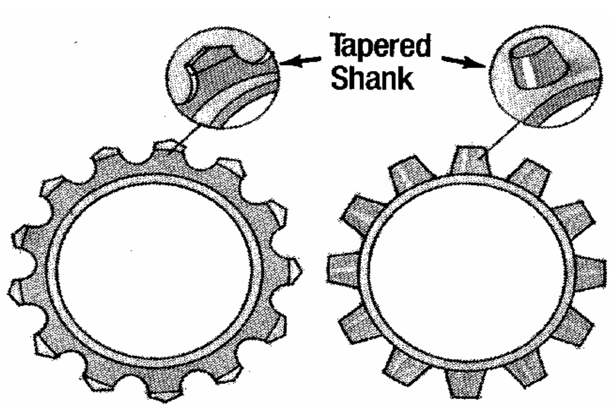


TAMPING FOOT COMPACTOR

PAD CONFIGURATION

Tamping foot **Pad foot**





TAMPING FOOT COMPACTOR

It is suitable for compacting all fined-grained soils, but is generally not suitable for use on cohesionless granular soils.

TAMPING FOOT COMPACTOR

This roller compacts the soil from the bottom of the lift to the top.

Lift thickness is generally limited to 8 inches compacted depth.

TAMPING FOOT COMPACTOR

- This type roller does not adequately compact the upper 2 or 3 inches of a lift.
- Therefore, for the last lift it should be followed with a pneumatic or smooth-drum roller.

TAMPING FOOT COMPACTOR

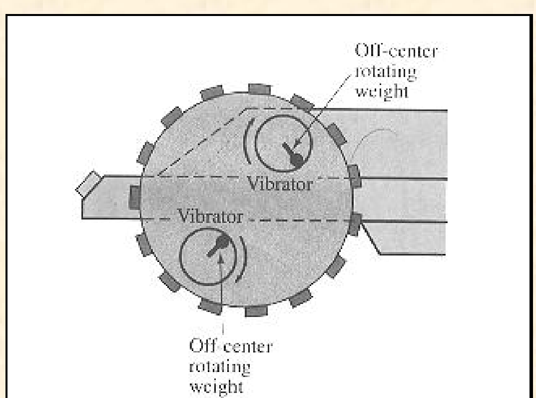
VIBRATORY ROLLERS

- Vibratory rollers are very efficient in compacting granular soils.
- Vibrators can be attached to the following rollers:
  - ✓ smooth-wheel rollers.
  - ✓ pneumatic rubber-tired rollers.
  - ✓ sheepsfoot rollers.

VIBRATORY ROLLERS

- Principles of Vibratory Rollers

The vibration is Produced by rotating off-center weights



VIBRATORY SOIL COMPACTOR

SMOOTH DRUM VIBRATORY SOIL COMPACTOR

This roller uses vibratory action in conjunction with ballast weight of the drum to compact.

SMOOTH DRUM VIBRATORY SOIL COMPACTOR

- One of the most effective means of attaining density for cohesionless materials.
- It is a relatively light roller, therefore maximum loose-lift depth is 9 inches.

VIBRATORY SOIL COMPACTOR

DUAL-DRUM VIBRATORY COMPACTOR

DUAL-DRUM VIBRATORY COMPACTOR

Use this roller to compact cohesionless subgrade, base courses, wearing surfaces, and asphalt.

DUAL-DRUM VIBRATORY COMPACTOR

Because it compacts from the top down, only relatively shallow lifts (less than 4 inches) can be worked.

ROLLERS PRODUCTION ESTIMATING

- The production formula for a compactor is given as

$$\text{Compacted Volume (cu yd) per hour} = \frac{W \times S \times L \times 16.3}{P} \qquad \textbf{(39)}$$

where

W = compacted width per roller pass, ft
S = average roller speed, mph
L = compacted lift (layer) thickness, in
P = number of passes required to achieve the required density

Note:The computed production in above equation is in cubic yards. It is necessary to apply shrinkage factor to convert it to bank cubic yard

Example 8

- A self-propelled tamping foot compactor will be used to compact a fill being constructed of clay material. Field tests have shown that the required density can be achieved with four passes of the roller operating at an average speed of 1.5 mph. The compacted lift will have a thickness of 5 in. The compacting width of this machine is 7 ft. One bcy equals

Example 8 (cont'd)

0.83 compacted cubic yards. The scraper production estimated for the project is 510 bcy per hour. How many rollers will be required to maintain this production?

$$\text{Compacted Volume (cu yd) per hour} = \frac{W \times S \times L \times 16.3}{P} = \frac{7(1.5)(5)16.3}{4} = 214 \text{ cy yd /hr}$$

$$\text{Volume in bcy} = \frac{214}{0.83} = 258 \text{ bcy/hr}$$

$$\text{Number of rollers needed} = \frac{510}{258} = 1.98 \approx 2 \text{ rollers}$$

DYNAMIC COMPACTION

- Dynamic compaction is a technique that has gained popularity in the U.S. for the densification of granular soil deposits.
- The method can produce densification to depth greater than 35 ft

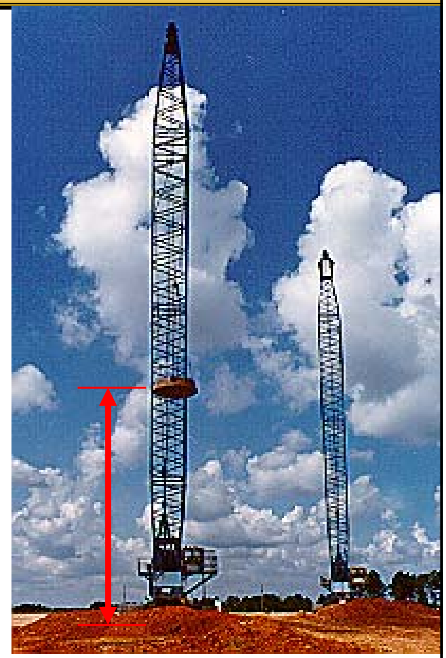
DYNAMIC COMPACTION

- This process primarily consists of dropping a heavy weight repeatedly on the ground at regular intervals.
- The weight of the hammer varies over a range of 18 to 80 kips.
- The height of the hammer drop varies between 25 to 100 ft.
- Conventional cranes are used to drop the weights.

DYNAMIC COMPACTION

This is a
20 ton weight

from 42 feet



DYNAMIC COMPACTION

Usually only make contact with about 50% of the actual ground surface being compacted.

DYNAMIC COMPACTION

Can achieve densification to a depths of about 30 ft using 30 ton weights and 100 ft drop heights.

DYNAMIC COMPACTION

- The degree of compaction achieved at a given site depends on the following factors:
  - ✓Weight of the hammer.
  - ✓Height of the hammer drop.
  - ✓Spacing of the locations at which the hammer is dropped.

DYNAMIC COMPACTION

- The significance depth of influence for compaction can be given approximately by the following expression:

$$D = n\sqrt{WH} \qquad \textbf{(40a)}$$

where

D = depth of improvement or significant depth (m)
n = an empirical coefficient (≈0.5)
W = dropping weight (metric ton)
H = height of drop (m)

DYNAMIC COMPACTION

- The significance depth of influence for compaction can also be given in English units as

$$D = 0.61\sqrt{WH} \qquad \textbf{(40b)}$$

where

D = depth of improvement or significant depth (ft)
W = dropping weight (kip)
H = height of drop (ft)

Example 9

- For a dynamic compaction test we are given: weight of hammer = 33,070 lb, and the height of drop = 40 ft. Determine the significant depth of influence for compaction in feet?

$$33{,}070 \text{ lb} = 33.07 \text{ kip}$$

$$D = 0.61\sqrt{WH} = 0.61\sqrt{33.07(40)} = \boxed{22.2 \text{ ft}}$$

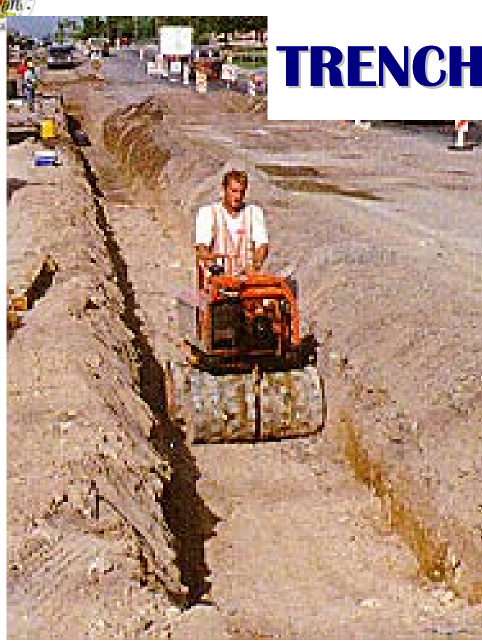
VIBRATORY PLATE COMPACTOR

For granular soils and asphalt.

RAMMER

Also known as a backfill tamper. Self-contained hand operated for use in confined spaces.

TRENCH ROLLER



WHEEL ATTACHMENT COMPACTORS

SOIL STABILIZATION

- Admixtures are used to stabilize soils in the field.
- Most common of these admixtures are:
  - ✓lime
  - ✓Lime-fly ash
  - ✓cement

SOIL STABILIZATION

- The main purpose of soil stabilization are to:
  - ✓ **modify the soil.**
  - ✓ **expedite construction.**
  - ✓ **improve the strength and durability of the soil.**